Expert Report to the NSW IPC on the Greenhouse Gas and Climate Implications of the Narrabri Underground Mine Stage 3 Extension

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1 Preliminaries

1) This expert report (hereafter, this Report) is a response to a brief provided to me by Environmental Defenders Office (EDO) on 28 January 2022. Said brief (hereafter the EDO Brief) is annexed to this report as Appendix A.

2) As detailed in the EDO Brief, I understand that this Report has been requested by EDO on behalf of its client Lock the Gate in relation to Narrabri Coal Operations Pty Ltd's proposed Narrabri Underground Mine Stage 3 Extension Project (SSD 10269), hereafter after the Project. In particular, my independent and expert advice is sought with regard to greenhouse gases and any climate change impacts that would arise from the Project.

3) I have reviewed Division 2 of Part 31 of the *Uniform Civil Procedure Rules 2005 (UCPR),* and the Expert Witness Code of Conduct contained in Schedule 7 of the UCPR, both of which govern the use of expert evidence in NSW Courts, and I agree to be bound by them in this Report. Specifically, I understand and agree to comply with the expectation that *``An expert witness is not an advocate for a party and has a paramount duty, overriding any duty to the party to the proceedings or other person retaining the expert witness, to assist the court impartially on matters relevant to the area of expertise of the witness.''*

4) External sources used in this Report are referenced. Unless otherwise indicated, modelling work presented in these external sources is taken at face value, as verifying the results is beyond the scope of this Report. Where relevant, underlying assumptions are noted.

5) A curriculum vitae of my relevant qualifications and experience is attached as Appendix B to this report.

2 Executive Summary

6) The primary conclusions of this Report are presented below. Sections of the Report that contain more detail are listed in brackets after each main point.

7) Greenhouse gases (GHG) emitted by human activities are responsible for essentially all of the global warming driving climate change. [Sections 3.1 and 3.3]

8) The primary anthropogenic GHGs are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Atmospheric concentrations of all these gases have risen dramatically since the 1960s at an accelerating rate. The level of CO_2, the most important GHG driving current climate change, is now higher than at any other time humans have inhabited Earth. [Section 3.1]

9) About 90% of the CO_2 emitted by humans per year is from the burning of fossil fuels: coal, gas, and oil. [Section 3.2]

10) Unabated climate change is likely to be greatest overall threat to the environment and people of New South Wales (NSW) because it is comprehensively dangerous, global, fundamental, rapid, compounding, self-reinforcing, has delayed effects and, in some cases, is irreversible. [Section 4]

11) The current level of global warming is about 1.2 degrees Celsius (°C) above preindustrial times. For comparison, the temperature difference between ice ages and the intervening periods is about 4°C – 6°C. [Sections 4 and 5.1]

12) Continued warming increases the risk that some subsystems of the Earth will cross `tipping points' that would cause irreversible changes. Some subsystems already show signs of approaching these transitions, which could accelerate climate change and greatly intensify its impacts, perhaps irreversibly. [Section 4.9]

13) Current effects of climate change worldwide include increased severity of storms and heat waves, species extinction, wildfires, coastal inundation from rising sea levels and increased storm surge. [Section 5.1]

14) Climate changes are happening rapidly. Examples include:

a) The Earth's energy imbalance was estimated in mid-2019 to be about 2 to 3 times what it was in mid-2005.

b) The past seven years have been the hottest seven years on record.

c) Precipitation, heat, and wildfire records have broken across all areas of the globe over just the last two years.

d) In the five years 2016 – 2020, only 18 days, on average, separated different billion-dollar weather and climate disasters in the US. [Section 5.1]

15) Australia is already experiencing dramatic climate change consequences. Most years in Australia are now warmer than almost any year in the 20th Century. Long-term increases in extreme fire weather and fire-season length are seen across the country. Flash droughts now happen so quickly that farmers find it difficult to adapt. Three billion individual native vertebrates perished in the Black Summer fires. Australians are five times more likely to be displaced by a climate-fuelled disaster than someone living in Europe. [Section 5.2]

16) NSW has borne the brunt of many of these changes. For example, 37% of the State's rainforests were fire-affected during Black Summer, including over half of the Gondwana Rainforests. In some cases, local tipping points in these forests may have already been crossed. The short-term NSW health costs associated with smoke exposure is estimated to be $1.07 billion, more than any other State. [Section 5.2.1]

17) The cost of extreme weather disasters in Australia has more than doubled since the 1970s, reaching $35 billion for the decade 2010-2019. Australia has been rated fourth highest in the G20 for economic losses per unit of GDP incurred from extreme weather events over the last 20 years (1999-2018). [Section 5.2]

18) The trajectory of human emissions, particularly between now and 2030, is the most important determinant of how much more climate change is in store. Already, human choices have essentially ensured that 1.5°C of warming will happen in the next two decades. If the trend of rising emissions continues, in just 80 years global warming could be 3°C – 4°C above pre-industrial temperatures. [Section 6.1]

19) Climate impacts are hitting harder and sooner than previous scientific assessments have expected. In parts of NSW, some effects of climate change are already surpassing future

2030 projections published only two years ago for medium and high emission scenarios. [Sections 6.2 and 6.4]

20) Future impacts depend on the level of warming that is reached, some of which are detailed in Table 1 below. [Sections 5 and 6]

Table 1: Consequences of Global Warming at Different Levels

Warming above the pre-industrial epoch	Some of the Impacts
1.1 – 1.2°C	***This is the current level of warming.*** 47% of local extinctions reported across the globe during last century can be attributed to climate change. Millions of people are now displaced annually because of weather/climate disasters. Peak heatwaves that occurred only once per 30 years in pre-industrial times in Australia, can now be expected every 5 years. Most years in Australia are now warmer than almost any year in the 20th century. Some NSW forests are near, or have already crossed, local tipping points that would irretrievably alter those ecosystems. Agricultural areas in NSW now experience runoff reduced by 15%, on average. The frequency of very warm days in Australia has increased approximately fivefold compared to the period 1960-1989. Black Summer wildfires occur in Australia in 2019-20. Similar fires happen in California in 2020 and 2021. Temperatures reach 38°C above the Arctic Circle in 2020, and reach 50°C in Canada in 2021.
1.5°C	***This level of warming will almost certainly be reached, as early as sometime in the 2030s.*** Peak heatwaves that occurred only once per 30 years in pre-industrial times in Australia, can be expected every 2.7 years. 6% of insects, 8% of plants, and 4% of vertebrates lose over half of their climatically-determined geographic living area. What used to be Australia's hottest year on record (2019) is now an average year. NSW has 2 – 4 more heatwave days per year than it currently experiences.
2.0°C	***This level is above the Paris Agreement goal of "holding the increase in global average temperature to well below 2°C above pre-industrial levels".*** 13% of the Earth's surface undergoes complete ecosystem transformations. 99% of the world's coral reefs, including the Great Barrier Reef, are eliminated. The number of insects, plants and vertebrates losing over half of their habitat doubles compared to losses at 1.5°C.

2.0°C (cont.)	Moderate risk of large-scale singular events leading to climatic tipping points. The world's most vulnerable people experience compounding crisis upon crisis. In Australia, considerably higher risk of impacts compared to 1.5°C with regard to: a) Water stress and drought, b) Shifts in biomes in major ecosystems, including rainforests, c) Changes in ecosystems related to the production of food, d) Deteriorating air quality, e) Declines in coastal tourism, f) Loss of coral reefs, sea grass and mangroves, g) Disruption of marine food webs, loss of fin fish, and ecology of marine species, h) Heat related mortality and morbidity, and i) Ozone-related mortality. Black Summer-like weather conditions are four times more common than in 1900. Sydney and Melbourne experience summer temperatures of 50°C. NSW has 4 - 8 more heatwave days per year than it currently experiences. Agricultural areas in NSW experience runoff reduced by 30%.
3.0°C – 4.0°C	***This level of warming could be a consequence of the world continuing with its current policy settings regarding GHG emissions.*** Most of the world's ecosystems are heavily damaged or destroyed. Extreme weather events are far more severe and frequent than today. Large areas of the world become uninhabitable, causing migration and conflict. Aggregated global impacts significantly damage the entire global economy. Peak heatwaves that occurred only once per 30 years in pre-industrial times in Australia expected annually. Megafires to occur in southeast Australia irrespective of whether drought occurs simultaneously. Many locations in Australia become uninhabitable due to water shortages. Many Australian properties and businesses are uninsurable. Severe impacts to both flora and fauna cause many of Australia's ecological systems to become unrecognisable. Sea level rise transforms Australia's coastal regions, putting the health and wellbeing of many people at severe risk. NSW has one to two more heatwave weeks per year than it currently experiences. Agricultural areas in NSW experience runoff reduced by 45-60%. Moderately high risk that a cascade of tipping points in the climate system drives the Earth system into a Hothouse Earth state not seen for millions of years, irrespective of humanity's late attempts to reduce emissions.

21) The world is emitting greenhouse gases on a trend that would lead to substantially more dangerous climate change. Nations that have committed to reducing emissions by 2030 have done so on average by only 7.5%, whereas a 30% reduction (on 2010 levels) is needed to limit warming to 2°C and a 55% reduction is needed to limit warming to 1.5°C. Australia's 2030 emissions reduction target is consistent with global warming of 4°C if all other countries followed a similar level of ambition. [Sections 7.1 and 7.4.1]

22) Based on current *policies* as opposed to Paris Agreement *pledges*, warming could go as high as 3.6°C. [Section 7.1]

23) Only about 8 years remain at current emission levels before the remaining global carbon budget to hold warming to 1.5°C with at least a 67% chance is exhausted. Australia's and NSW's `share' of this budget would be exhausted in 3 and 4 years, respectively. [Sections 7.2 and 7.4.2]

24) In order to have even a 50% chance of holding warming to 1.5°C, 58% of oil, 59% of fossil methane gas, and 89% of coal reserves must not be extracted. Despite this, governments are still planning to produce about 45% more fossil fuels by 2030 than would be consistent with a 2°C pathway and more than double than would be consistent with a 1.5°C pathway. [Section 7.3]

25) NSW could play a major role in limiting climate change by quickly reducing its production of fossil fuels, particularly those which are exported. The emissions caused by combusting the black coal NSW produces are three times more damaging to the NSW environment than its own direct emissions. [Section 7.5.3]

26) Scope 1 and Scope 2 emissions from this Project alone would make it one and one-half times more difficult for Australia to meet its 2030 emissions target. The Project's Scope 1 emissions would make it one and one-quarter times more difficult for NSW to meet its 2030 target. Furthermore, the Project may continue to generate emissions after closure. [Section 8.2]

27) The Project is inconsistent with holding global warming to well below 2°C. [Section 8.3]

28) From a scientific perspective, all emissions, including Scope 3 emissions released when fossil fuels are combusted by any end user, must be included when considering

environmental and social effects, including local environmental and social effects. To do otherwise is to assume that the fuel is never used for its intended purpose. [Section 8.4.1]

29) The `Social Cost of Carbon is the value of the net damage caused to society by adding a tonne of $CO_2$ into the atmosphere. It is not same as a `price on carbon' that may be introduced by government policies or prices related to emissions trading schemes or carbon `offsets.' These are policy instruments, not assessments of climate damage. [Section 8.4.2]

30) Applying a recent median scientific value for the Social Cost of Carbon to the full (all Scopes) lifetime emissions of the Project yields at least 296 billion AUD of global damages. Apportioned to NSW on the basis of fraction of world economy, the cost to NSW of the GHGs resulting from approval of the Project would be in excess of 917 million AUD, more than 1000 times the amount stated in the Project EIS. [Section 8.4.2]

31) The recommended Conditions of Approval would not significantly reduce Scope 1 and Scope 2 GHG emissions from that indicated in the Project EIS, and in fact, allow the possibility that they could be increased. Importantly, the Conditions of Approval do not address the most important component of the Project's emissions that affect the environment of NSW: Scope 3 emissions. [Section 8.4.3]

32) If the Project were approved now – 9 years before the current mining approval ends – the government and people of NSW would be disadvantaged by not having access to critical information that may affect the decision, including a much better indication of the future market for coal, the results of future studies and research aimed at reducing fugitive methane emissions, and a secure indication of whether or not the State's 2030 emissions target will be met. [Section 8.4.3]

33) An argument that Project emissions represent a very small fraction of national or global emissions is irrelevant and misleading. If individual consent authorities around the world were to accept this argument and act upon it to approve fossil fuel expansion projects, the climate change predicament would, *per force*, continue to worsen. [Section 8.4.4]

34) The climate change externalities of the Project will be borne disproportionately by younger and future generations, with no clear recourse or path to remediation. [Section 8.4.4]

3 Causes of Anthropogenic Climate Change

35) ***Anthropogenic* climate change is change in the Earth's climate caused by *human activities* that release additional greenhouse gases (GHGs) into the atmosphere or alter the natural land and ocean sinks for these gases**. GHGs trap energy that would otherwise escape from the Earth's upper atmosphere. The additional GHGs caused by human activity create an energy imbalance that produces global warming of the Earth's surface, which drives climate change.

3.1 Increases in greenhouse gases drive global warming

36) GHGs have kept the Earth's surface at temperatures suitable for modern human civilisation and agriculture for thousands of years. Since industrialisation, however, and in particular over the last 70 years, **human activities have upset this long-standing balance, by increasing the amount of GHGs in the atmosphere. Extra energy is returned to the Earth's surface, causing the global warming that fuels changes in the global climate.**

37) The primary GHGs driving current human-caused climate change are **carbon dioxide (CO_2)**, **methane (CH_4)**, and **nitrous oxide (N_2O)**. These gases differ in their concentration in the atmosphere, residence time in the atmosphere, and potential to cause a given amount of warming per weight. Of these, **atmospheric concentration is the only property of GHGs that can be significantly influenced by humans**.

38) Excess amounts of CH_4 and N_2O persist in the atmosphere for about 12 and 109 years, respectively.[1] The life cycle of atmospheric CO_2 is more complex. **Most of the carbon dioxide that is not absorbed quickly by ocean and land 'sinks' will remain in the atmosphere for thousands of years.**[2] This is the primary reason why **most long term global warming is caused by increases in the amount of CO_2 in the atmosphere**.

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[1] Forster P., T. et al. (2021) The Earth's energy budget, climate feedbacks, and climate sensitivity, Chapter & of Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Table 7.15, accessed at: https://www.ipcc.ch/report/sixth-assessment-report-working-group-i/

[2] IPCC 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., et al, eds]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA http://www.climatechange2013.org/images/report/WG1AR5_ALL_FINAL.pdf

39) Due to their different chemical properties and residency times in the atmosphere, GHGs have different global warming potentials (GWPs), that is, they differ in the amount of heat they trap over a given period of time after they are emitted. Over a 20-year period, fossil methane[3] is 82.5 times more effective than CO_2 in trapping heat, and 29.8 times more effective over 100 years. Nitrous oxide has a global warming potential about 273 times that of CO_2 on timescales of 20 to 100 years.[4]

40) Whilst GHGs remain in the atmosphere, they continue to contribute to global warming, year after year, regardless of when they were emitted. This means that **the full effect of past GHG emissions is yet to be felt**, as the Earth continues to warm under the influence of historical emissions (particularly CO_2) as well as those emitted in the current year.

41) **Atmospheric concentrations of CO_2, CH_4 and N_2O have risen since the industrial revolution, with dramatic upward increases of CO_2 beginning around 1960** (Fig. 1).[5]

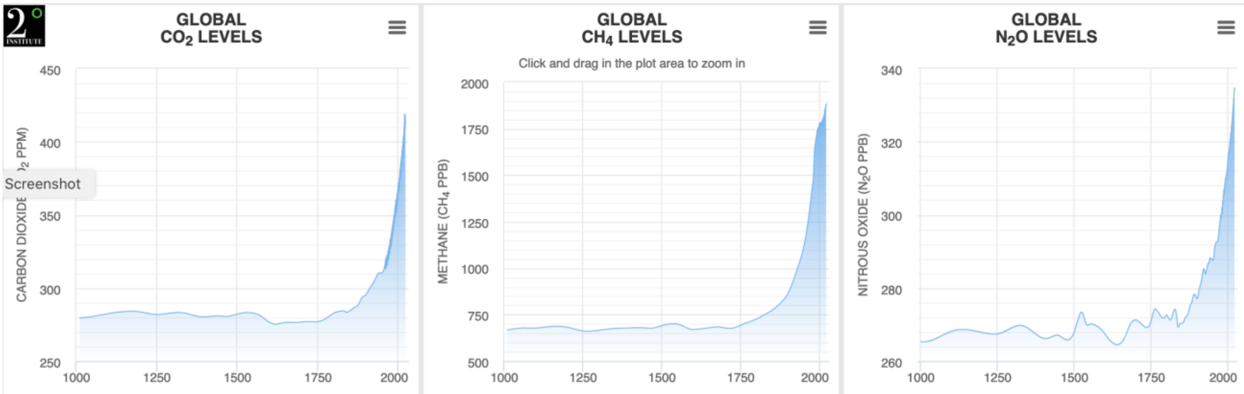

Fig. 1: The rise of GHGs in the atmosphere from 1000AD to present. Graph prepared by the Two Degree Institute, based on ice core records (CSIRO) and in situ measurements (Scripps).

[3] Note: Fossil methane has a higher GWP than other sources of CH_4 because it results in fossil carbon added to the atmosphere, which was not previously part of the carbon cycle of the atmosphere. The GWPs for *non-fossil* CH_4 is 80.8 and 27.2 on 20 and 100-year timescales, respectively.

[4] Forster P., T. et al. (2021) The Earth's energy budget, climate feedbacks, and climate sensitivity, Chapter 7 of Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Table 7.15, accessed at: https://www.ipcc.ch/report/sixth-assessment-report-working-group-i/

[5] 2 Degrees Institute (2020) Accessed at: https://www.climatelevels.org/

42) Current levels of CO_2, CH_4 and N_2O in the atmosphere are about 147%, 256% and 123%, respectively, of their pre-industrial levels around 1750.[6]

43) **The rate at which atmospheric concentrations of the main GHGs is increasing is *itself* increasing**, as illustrated in Fig. 2 at right.[7]

44) The **current level of atmospheric CO_2 is** about 415 parts per million (ppm), **25% higher than any other time since the mid-Pliocene, about 2 million years ago,**[8] and **concentrations of CH_4 and N_2O are higher than at any time in at least 800,000 years.**[9] See Fig. 3 below.

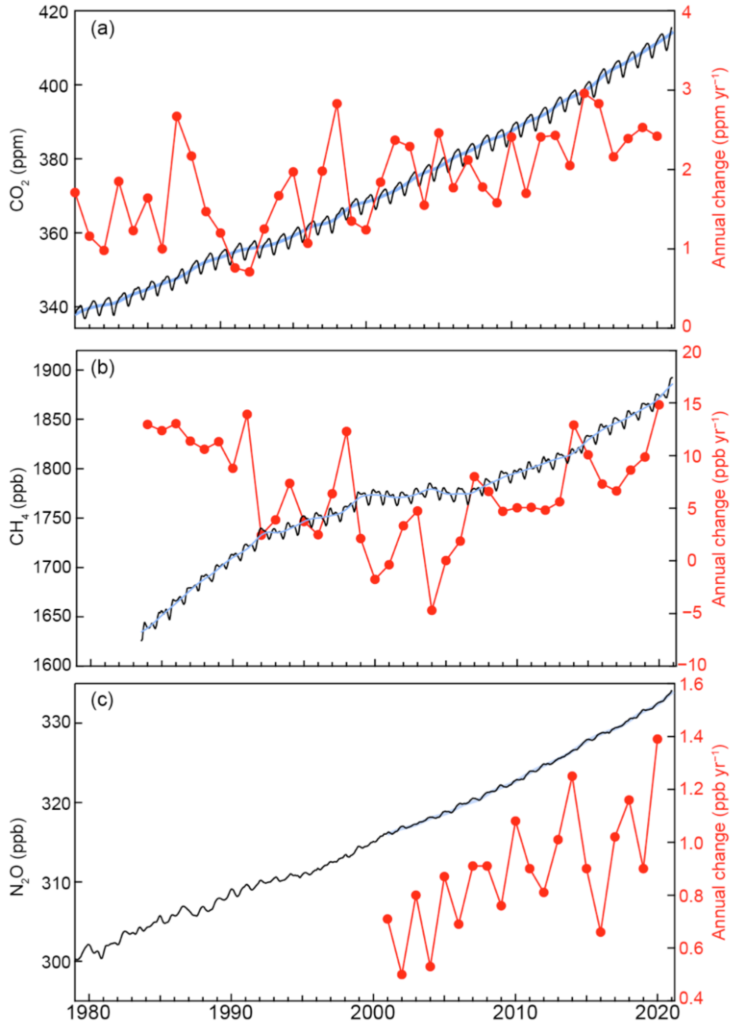

Fig.2: Dark lines: Increases in the atmospheric concentration of CO_2, CH_4 and N_2O from 1980 to 2020. Note that the vertical scales do not start at zero. Red lines: Increases in each year compared to the previous year. This figure derives from Figure 2.50 of Blunden and Boyer (2020).

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[6] IPCC (2021) Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, accessed at: https://www.ipcc.ch/report/ar6/wg1/#SPM

[7] Blunden, J. and T. Boyer, eds. (2020) State of the Climate in 2020 in *Bull. Amer. Meteor. Soc.*, 102 (8), Si–S475, https://doi.org/10.1175/2021BAMSStateoftheClimate.1

[8] Fedorov, A.V. et al (2013) Patterns and mechanisms of early Pliocene warmth, in Nature, 496, doi:10.1038/nature12003.

[9] IPCC (2021) Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, accessed at: https://www.ipcc.ch/report/ar6/wg1/#SPM

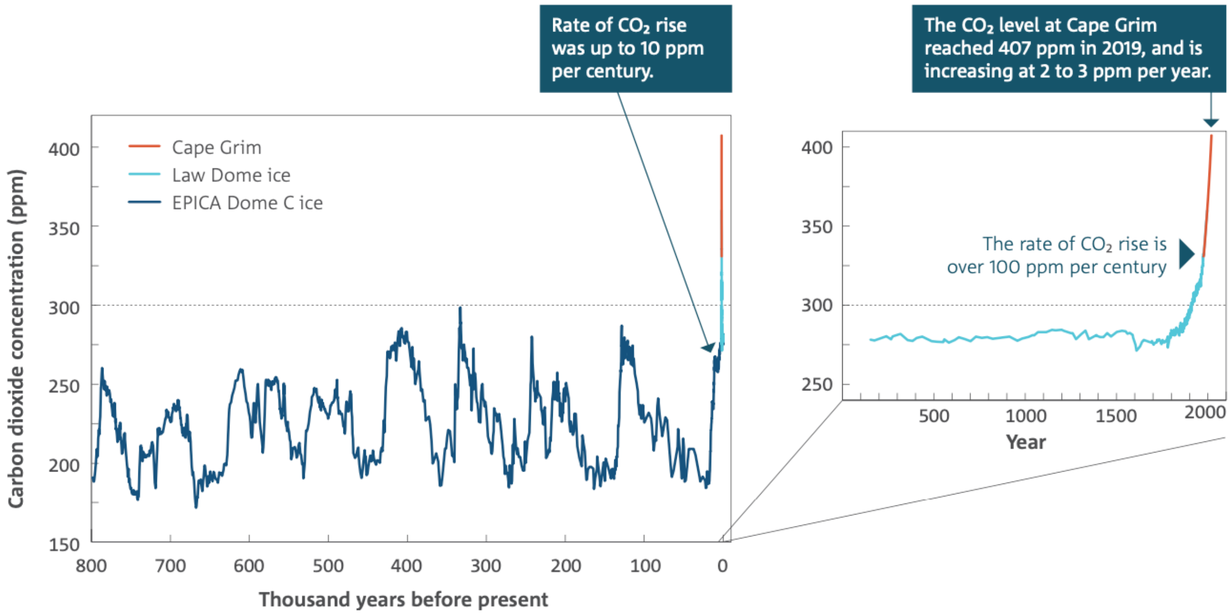

Fig. 3: Current increases in atmospheric CO_2 compared to last 800,000 years. Figure from CSIRO/BOM (2020).

45) For perspective, the species *Homo sapiens* (modern human) is believed to have arisen only 300,000 to 600,000 years ago. In other words, **carbon dioxide levels are higher now than at any other time our species has inhabited the Earth**. (See Fig. 3 above.)[10]

46) **Since 1970, the global average surface temperature has been rising at a rate** of 2.0°C per century,[11,12] **about 200 times faster than the average rate of change** of about 0.01°C per century **for the last 7,000 years.**[13]

[10] CSIRO/BOM (2020), State of the Climate 2020, Commonwealth of Australia. http://www.bom.gov.au/state-of-the-climate

[11] NOAA (2016) State of the Climate: Global Analysis for Annual 2015. National Centers for Environmental Information, available at http://www.ncdc.noaa.gov/sotc/global/201513

[12] IPCC SR1.5 (2018) Intergovernmental Panel on Climate Change Special Report on Global Warming of 1.5°C. Accessed at: http://ipcc.ch/report/sr15/

[13] Marcott SA, Shakun JD, Clark PU, Mix A (2013) A reconstruction of regional and global temperature for the past 11,300 years. *Science* 339:1198-1201

3.2 Human greenhouse gas emissions come primarily from fossil fuels

47) **At present, about 90% of the additional CO_2 emitted per year is from the burning of coal, gas, and oil,**[14] with most of the remainder due to land use changes (e.g., deforestation which removes a natural sink for CO_2).

48) **Human CO_2 emissions from fossil fuel use continue to rise,** although at a smaller rate than in the first decade of this century.**[15]** (See Fig. 4.)[16]

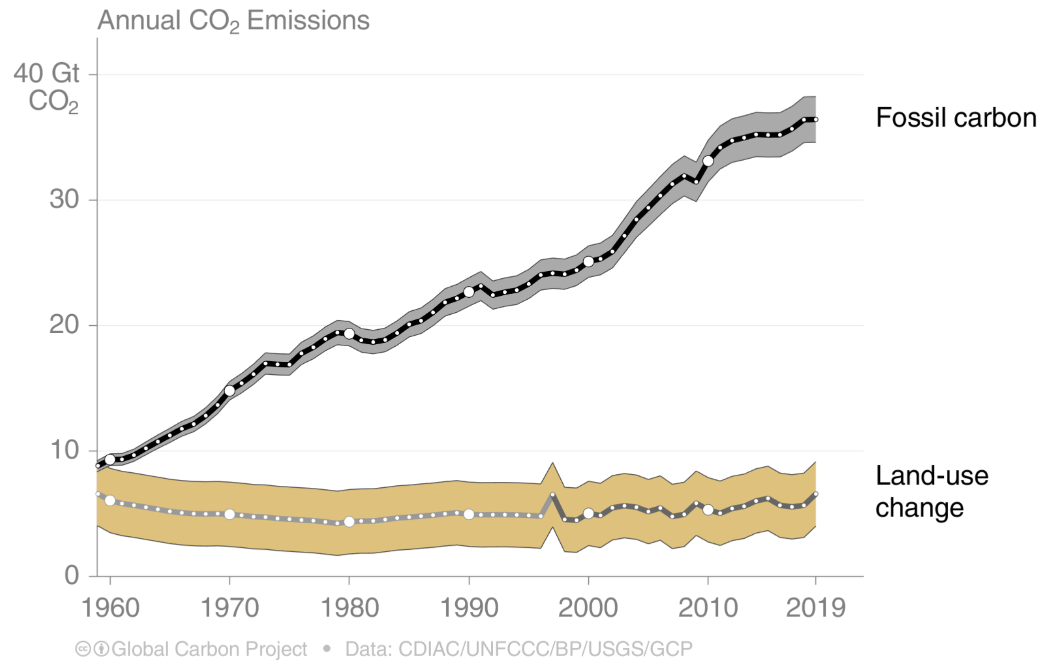

Fig. 4: Global human emissions from fossil sources continue to grow, whilst those from land-use changes (primarily deforestation) have remained relatively constant. Combined, humans emitted about 42 billion tonnes (Gt) of CO_2 into the atmosphere in 2019. Data from Friedlingstein et al (2020).

49) The growing trend in emissions continues: **year-on-year CO_2 emissions from fossil fuels are now more than 300% of 1960s levels.**[17]

[14] Friedlingstein, P et al. (2021) Global Carbon Budget 2021, Earth Syst. Sci. Data. See their Table 6, https://essd.copernicus.org/preprints/essd-2021-386/
[15] Friedlingstein, P et al. (2020) Global Carbon Budget 2020, Earth Syst. Sci. Data, 12, 3269-3340. https://doi.org/10.5194/essd-12-3269-2020
[16] Figure is from the Global Carbon Project (2020), Accessed at : https://www.globalcarbonproject.org/carbonbudget/20/presentation.htm
[17] Friedlingstein, P et al. (2019) Global Carbon Budget 2019, Earth Syst. Sci. Data, 11, 1783–1838, See their Table 6, https://doi.org/10.5194/essd-11-1783-2019

50) The production, delivery and combustion of **fossil fuels is also associated with the release of CH_4.**[18] **A recent surge in atmospheric methane over the past decade is attributed in equal parts to agriculture (particularly livestock) and fossil fuels**.[19]

51) Restrictions imposed in response to **COVID-19** are responsible for annual human GHG emissions decreasing by about 7% in 2020,[20] a result that **will have negligible impacts in terms of climate change.**[21] It is estimated that Australian GHG emissions will be 4.5% lower in 2020 than in 2018, but will likely rebound in 2021 to the trend observed prior to 2018.[22] After the Global Financial Crisis of 2008-2009, global CO_2 emissions from fossil-fuel combustion and cement production grew 5.9% in 2010, more than offsetting the 1.4% decrease in 2009.[23]

3.3 Humans are the cause of essentially all currently observed global warming

52) **Nearly all of the warming experienced in past 160 years is due to human activities**, with natural forces (volcanos, changes in solar radiation, etc) playing a negligible role.[24]

53) According to most recent report (Assessment Report 6 from Working Group 1, AR6 WG1)[25] of the United Nations' Intergovernmental Panel on Climate Change (IPCC) (my emphasis):

   a) "It is **unequivocal that human influence has warmed the atmosphere, ocean and land**" and

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[18] WMO 2019, United in Science, Report prepared for the UN Climate Action Summit 2019, https://wedocs.unep.org/bitstream/handle/20.500.11822/30023/climsci.pdf

[19] Jackson, RB et al. (2020) Increasing anthropogenic methane emissions arise equally from agricultural and fossil fuel sources, Environ. Res. Lett., 15, 071002, https://doi.org/10.1088/1748-9326/ab9ed2

[20] Friedlingstein, P et al. (2020) Global Carbon Budget 2019, Earth Syst. Sci. Data, 12, 3269-3340, https://doi.org/10.5194/essd-12-3269-2020

[21] CSIRO/BOM (2020), State of the Climate 2020, Commonwealth of Australia. http://www.bom.gov.au/state-of-the-climate

[22] Sadler, H. (2021) National Energy Emissions Audit, The Australia Institute, Accessed at: https://australiainstitute.org.au/report/national-energy-emissions-audit-january-2021/

[23] Peters et al. (2012) Rapid growth in CO_2 emissions after the 2008–2009 global financial crisis, Nature Climate Change, 2, 2-4.

[24] Gillett, N.P. et al. (2021) Constraining human contributions to observed warming since the pre-industrial period, in Nature Climate Change, https://doi.org/10.1038/s41558-020-00965-9

[25] IPCC (2021) Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, accessed at: https://www.ipcc.ch/report/ar6/wg1/#SPM

b) "**Human influence has warmed the climate at a rate that is unprecedented in at least the last 2000 years**" and

c) "**Observed warming is driven by emissions from human activities**, with greenhouse gas warming partly masked by aerosol cooling."

54) **Reducing net anthropogenic GHG emissions to zero and maintaining them at that level is the only way that humans can stabilise the climate. The primary determinant of future climate change, beyond that which is already locked in by emissions to date, is the future trajectory of world emissions, especially the path between now and 2030**.[26] The more quickly emissions are brought and held to zero, the lower the peak global warming temperature will be.

4 Why Climate Change is Different to other Threats

55) **Scientists describe the amount of global warming by comparing the average global surface temperature of the Earth now to that in pre-industrial times** (often taken to mean prior to about 1850). An enormous amount of energy (heat) is required to raise the average surface temperature of the entire Earth by even a small amount. It is this large energy increase that drives the major changes in climate being experienced now, by `super-charging' the Earth's physical systems.

56) Consequently, **climate change impacts can be large even for rather small changes in the global surface temperature**. **The global average temperature difference between glacials (ice ages) and the periods in between (interglacials) is about 4 – 6°C** (Fig. 5).[27]

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[26] WMO (2019) United in Science, Report prepared for the UN Climate Action Summit 2019, https://wedocs.unep.org/bitstream/handle/20.500.11822/30023/climsci.pdf

[27] Henley, B. and Abram, N. (2017) https://theconversation.com/the-three-minute-story-of-800-000-years-of-climate-change-with-a-sting-in-the-tail-73368, and data sources and references therein

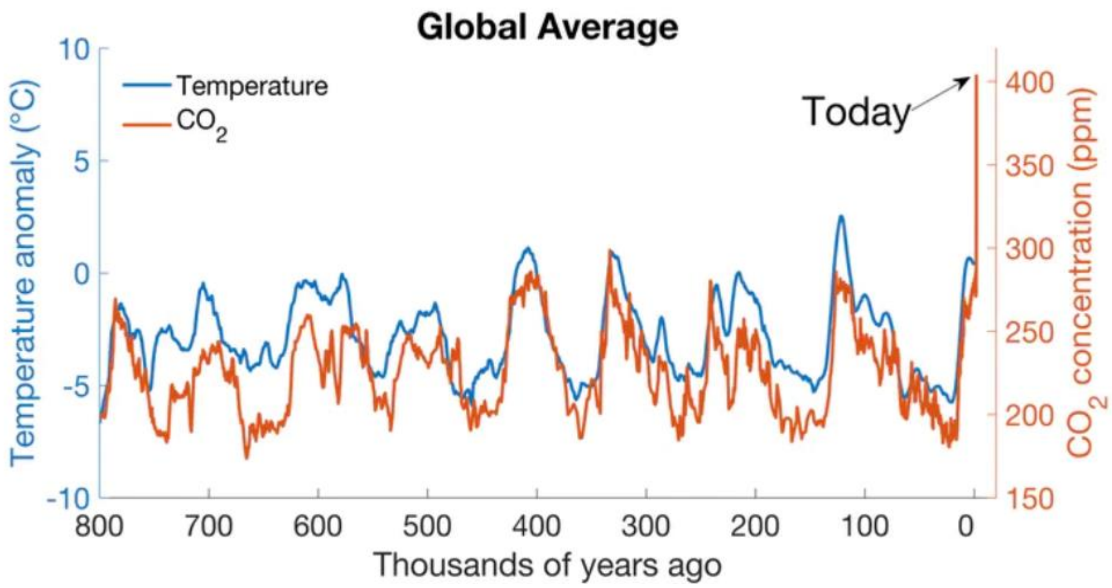

Fig. 5: Global average temperature difference (blue) and atmospheric concentration of CO_2 (orange) over the last 800,000 years. Low periods are ice ages, whilst high periods are interglacials; Only about 5°C separates the two. Plot from Henley and Abram (2017).

57) Unabated climate change poses an enormous threat to the environment and peoples of the world, Australia and NSW for several reasons that, when taken together, are unique to climate change. Unabated anthropogenic climate change is:

a) **Fundamental** – affecting basic aspects of the physical Earth system, and the ecosystems that depend on it,

b) **Global** – greenhouse gases emitted anywhere in the world affect the whole globe,

c) **Comprehensively Dangerous** – with the potential to disrupt or destroy nearly every ecosystem,

d) **Rapid** – occurring at a speed that precludes many organisms and even whole ecosystems from adapting,

e) **Inertial** – with a delayed response to emissions that `locks in' some measure of climate change greater than that currently experienced,

f) **Compounding** – the effects of climate change do not occur independently, but can occur simultaneously, greatly increasing the negative consequences of extreme events,

g) **Self-reinforcing** – many elements of the Earth System react to warming by releasing greenhouse gases, further accelerating climate change (positive feedback),

h) **Irreversible** – feedbacks may cause the crossing of tipping points, with the potential to irreversibly change ecosystems and processes in the Earth system, including the possibility of cascading to an unimaginably hostile world.

4.1 Climate change is fundamental to the environment

58) Over the last million or so years, the Earth system has travelled on bounded **pathways that connect glacial periods to warmer interglacial periods.** These pathways are not identical, but cycle about every 100,000 years.[28] (See Fig. 6 below.)

59) **The climate changes profoundly during each transition, reshaping the Earth's physical system and the life it supports.** Sea levels can change by 100m, the fraction of the Earth's surface covered with ice dramatically changes, and different species dominate the biosphere, on land and in the ocean. Yet these **hugely different versions of Earth are separated by only 4 – 6°C of average global temperature**.

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[28] Steffen W et al. (2018) Trajectories of the Earth System in the Anthropocene. Proc. Natl. Acad. Sci. (USA) doi:10.1073/pnas.1810141115 and references therein
https://www.pnas.org/content/pnas/115/33/8252.full.pdf

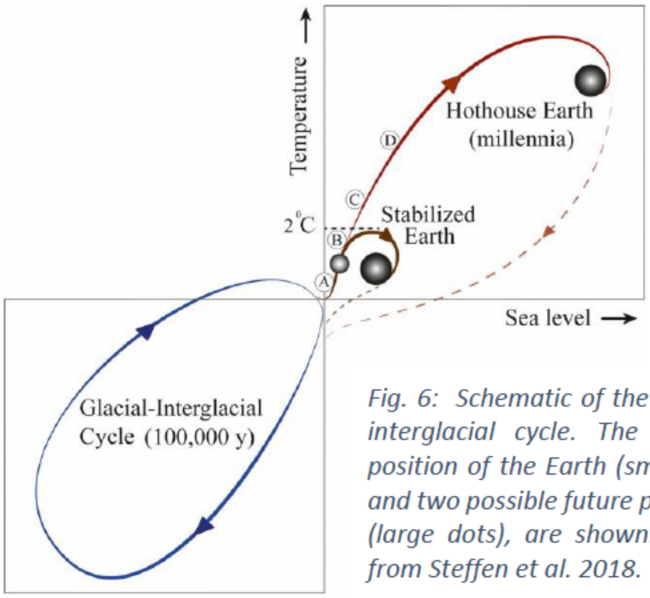

Fig. 6: Schematic of the glacial-interglacial cycle. The current position of the Earth (small dot) and two possible future positions (large dots), are shown. Figure from Steffen et al. 2018.

60) **Anthropogenic GHG emissions are now pushing the Earth System rapidly away from the glacial-interglacial cycle of stability** (see Fig. 6) **toward new, hotter climatic conditions and a profoundly different biosphere.**

4.2 Climate change is global

61) Due to the interconnectivity of the Earth's systems, **GHGs emitted anywhere are distributed throughout the atmosphere, where they contribute to the warming of the planet as a whole.** Thus, **the location, or the identity of the emitter, is of no consequence to the ultimate warming effect.** Australian emissions contribute to climate change impacts everywhere on Earth, and emissions from any location on Earth influence the effects that Australia experiences from climate change. **Humans bear collective responsibility for anthropogenic climate change.**

62) A very large number of small, individual human sources of greenhouse gases combine to form the collective global risk of climate change. **If every source of emissions that is a `small fraction of the whole' were to be ignored, the problem would persist.**

4.3 Anthropogenic change is comprehensively dangerous

63) **Current levels of greenhouse gases are already dangerous**: ecosystems are degrading and catastrophes due to extreme weather are occurring that can be directly attributed to

climate change. Recent IPCC reports[29,30] outline the comprehensive nature of the damage already being done by anthropogenic climate change across the whole of Earth's environmental systems, as well as that likely to occur in future if greenhouse gas emissions remain unchecked. Some of these effects are detailed in Section 5 of this Report. **Nearly every environmental system on Earth will be affected if global warming increases to 3°C – 4°C**.

4.4 Anthropogenic climate change is rapid

64) The dramatic changes that accompany the switch from a glacial to an interglacial period occur over tens of thousands of years with total temperature changes of about 5°C. **Yet in just 200 years humans have raised the average global temperature to more than 20% of this glacial-interglacial gap**, so that the Earth is now nearing the upper envelope of interglacial conditions over the past 1.2 million years.[31]

65) **The speed of this change makes it difficult, or in some cases impossible, for species and ecosystems to adapt. At 2°C of warming, 13% of the Earth's surface will undergo complete ecosystem transformations.**[32] **A study of 105,000 species found that even at 1.5°C of warming, 6% of insects, 8% of plants, and 4% of vertebrates are likely to lose over half of their climatically-determined geographical area. These percentages *double* for 2°C of warming.**[33]

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[29] IPCC SR1.5 (2018) Intergovernmental Panel on Climate Change Special Report on Global Warming of 1.5°C. Accessed at: http://ipcc.ch/report/sr15/

[30] IPCC (2014): Summary for policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Field et al. (eds.) Cambridge University Press, pp. 1-32.

[31] Steffen W et al. (2018) Trajectories of the Earth System in the Anthropocene. *Proc. Natl. Acad. Sci. (USA)* doi:10.1073/pnas.1810141115 and references therein https://www.pnas.org/content/pnas/115/33/8252.full.pdf

[32] IPCC SR1.5 (2018) Intergovernmental Panel on Climate Change Special Report on Global Warming of 1.5°C. Accessed at: http://ipcc.ch/report/sr15/

[33] Warren, R., J. Price, E. Graham, N. Forstenhaeusler, and J. VanDerWal (2018): The projected effect on insects, vertebrates, and plants of limiting global warming to 1.5°C rather than 2°C. Science, 360(6390), 791–795, doi:10.1126/science.aar3646.

66) A recent meta-analysis[34] of 27 studies concerning a total of 976 species found that **47% of local extinctions reported across the globe during last century could be attributed to climate change**.

4.5 Climate change has delayed effects

67) **The full climatic effects of greenhouse gases (especially CO_2) are not felt until long after the time of emission.** This means that a few tenths of a degree of additional warming above the present 1.1°C – 1.2°C are already locked as inertia in the Earth system responds to greenhouse gases that have already emitted.[35]

68) This, together with natural variability, means that **even with rapid reductions of about 5% per year (relative to the year previous) beginning in 2021, a drop in global average temperatures may not be reliably measured until about 2050**.[36] This is an example of how global emission decisions made in the period 1990 to 2020 have a delayed effect.

69) The amount of climate change expected in the next decade is similar under all plausible global emissions scenarios. However, by the mid-21st century, higher ongoing emissions of greenhouse gases will lead to greater warming and associated impacts, while reducing emissions will lead to less warming and fewer impacts.[37] **The lag between the full effects of emissions and the global warming they cause means that what we do this year has consequences for every year hereafter into the foreseeable future**.

4.6 Climate change is compounding

70) **The effects of climate change often compound one another**, acting to amplify deleterious effects. This includes instances where **multiple destructive events or elements occur at**

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[34] Wiens, J.J., 2016: Climate-Related Local Extinctions Are Already Widespread among Plant and Animal Species. PLOS Biology, 14(12), e2001104, doi:10.1371/journal.pbio.2001104.
[35] IPCC SR1.5 (2018) Intergovernmental Panel on Climate Change Special Report on Global Warming of 1.5°C. See their Fig. 1.5. Accessed at: http://ipcc.ch/report/sr15/
[36] Samset, BH, Fuglestvedt, JS and Lund, MT (2020) Delayed emergence of a global temperature response after emission mitigation. *Nature Communications,* 11, 3261, https://doi.org/10.1038/s41467-020-17001-1 (and references therein)
[37] CSIRO/BOM (2020) State of the Climate 2020, Commonwealth of Australia. http://www.bom.gov.au/state-of-the-climate/

the same time or in close succession, exacerbating one another such that the overall impact is worse than if each had occurred in isolation.[38]

71) For example, tropical storms are damaging not only due to high winds, but also due to accompanying storm surge caused by rising sea levels and a warming, wetter atmosphere. This can then cause coastal erosion and flooding with different and longer lasting consequences.

72) Another example is the drivers of interannual climate variability over southeast Australia, which do not operate independently of each other. This increases the chance of compounding effects on fire risk.[39] Further, pre-existing drought conditions and heatwaves often occur simultaneously with high fire danger days. This `triple whammy' effect has severe implications not only for the landscape and the ecosystems it supports, but also for humans working outside, on the land, and combating fires.

4.7 Climate change can be self-reinforcing

73) In some cases, the response of an Earth subsystem can enhance (or diminish) the effect of global warming itself. The physical, chemical and biological processes that cause these effects are called *feedbacks*.

74) ***Negative feedbacks* are those that act in the opposite sense of warming to restore Earth back to its original stability**. Examples include: the physics of (black body) radiation that increases the amount of outgoing radiation into space as the Earth warms, and the larger uptake of carbon by land forests and oceans as the Earth warms. Detailed climate models include these effects. Some negative feedback processes, such as the uptake of carbon by

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[38] Steffen, W. and Bradshaw, S. (2021) Hitting Home: The Compounding Costs of Climate Inaction, and references cited therein. Climate Council of Australia Ltd. Accessed at: https://www.climatecouncil.org.au/resources/hitting-home-compounding-costs-climate-inaction

[39] Abram, N.J., et al. (2021) Connections of climate change and variability to large and extreme forest fires in southeast Australia, Communications Earth & Environment 2:8, https://doi.org/10.1038/s43247-020-00065-8

forests, are losing strength, increasing the **risk that self-reinforcing mechanisms will counter efforts to mitigate further climate change, and instead accelerate it**.[40,41]

75) ***Positive feedbacks* are self-reinforcing mechanisms are that act to enhance warming to push Earth away from its previous (cooler) stability state.** A few examples that are already underway include:[42]

a) dieback of the Amazon and Boreal forests due to global warming, which decreases their ability to act as carbon sinks, and releases their stored CO_2 into the atmosphere,

b) thawing of frozen permafrost soil due to warming, which releases CO_2 and/or CH_4, depending on local conditions,

c) reduced spring snow cover in the Northern Hemisphere and loss of summer sea-ice in the Antarctic and Arctic, and long-term loss of polar ice sheets, which reduces the amount of sunlight reflected back into space, as well as allowing land ice to more easily escape to the sea, increasing sea levels.

76) The combined effect of all climate feedback processes is net positive, that is, acting to amplify the climate response.[43]

4.8 Some climate changes are irreversible

77) According to the sixth IPCC Assessment Report (AR6), "**Many changes due to past and future greenhouse gas emissions are irreversible for centuries to millennia, especially**

[40] Raupach MR, et al. (2014) The declining uptake rate of atmospheric CO2 by land and ocean sinks. Biogeosciences 11:3453–3475.

[41] WMO 2019, United in Science, Report prepared for the UN Climate Action Summit 2019, https://wedocs.unep.org/bitstream/handle/20.500.11822/30023/climsci.pdf

[42] Steffen W et al. (2018) Trajectories of the Earth System in the Anthropocene. Proc. Natl. Acad. Sci. (USA) doi:10.1073/pnas.1810141115 and associated Appendix https://www.pnas.org/content/pnas/115/33/8252.full.pdf

[43] Arias, PA et al. (2021) Technical Summary Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, accessed at: https://www.ipcc.ch/report/ar6/wg1/#FullReport

changes in the ocean, ice sheets and global sea level.”[44] Specifically, the AR6 lists the following:

a) Changes in global ocean temperature (*very high confidence*), deep ocean acidification (*very high confidence*) and deoxygenation (*medium confidence*) are irreversible on centennial to millennial time scales.

b) Mountain and polar glaciers are committed to continue melting for decades or centuries (*very high confidence*).

c) Loss of permafrost carbon following permafrost thaw is irreversible at centennial timescales (*high confidence*).

d) It is *virtually certain* that global mean sea level will continue to rise over the 21st century. In the longer term, sea level is committed to rise for centuries to millennia due to continuing deep ocean warming and ice sheet melt, and will remain elevated for thousands of years (*high confidence*).

4.9 Crossing climate tipping points could lead to a cascade to a `Hothouse Earth’

78) The **most devastating risk of continued global warming is that some of Earth’s subsystems** (e.g., Arctic sea ice, ocean circulation, the Amazon rainforest, or coral reefs, for example) **will become unstable and `tip’ irreversibly into new states that accelerate the effects of climate change**. Some of these subsystems are already showing signs of becoming unstable, with `tipping points’ that could lie on our current trajectory of global warming rising to 2°C, 3°C or 4°C above pre-industrial temperatures.[45,46]

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[44] IPCC (2021) Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, accessed at: https://www.ipcc.ch/report/ar6/wg1/#SPM

[45] Steffen W et al. (2018) Trajectories of the Earth System in the Anthropocene. Proc. Natl. Acad. Sci. (USA) doi:10.1073/pnas.1810141115 and associated Appendix, accessed at: https://www.pnas.org/content/pnas/115/33/8252.full.pdf

[46] Lenton, T. M., Rockström, J., Gaffney, O., Rahmstorf, S., Richardson, K, Steffen, W. & Schellnhuber, H.J. (2019) Nature, vol 575, pp 592 – 595.

79) *Tipping points*[47] in the Earth System refer to thresholds that, if crossed, would lead to far-reaching, and, in some cases, abrupt and/or irreversible changes in subsystems (called tipping elements). **The nature of tipping points is that they are irreversible on timescales associated with natural variability in the Earth System**.

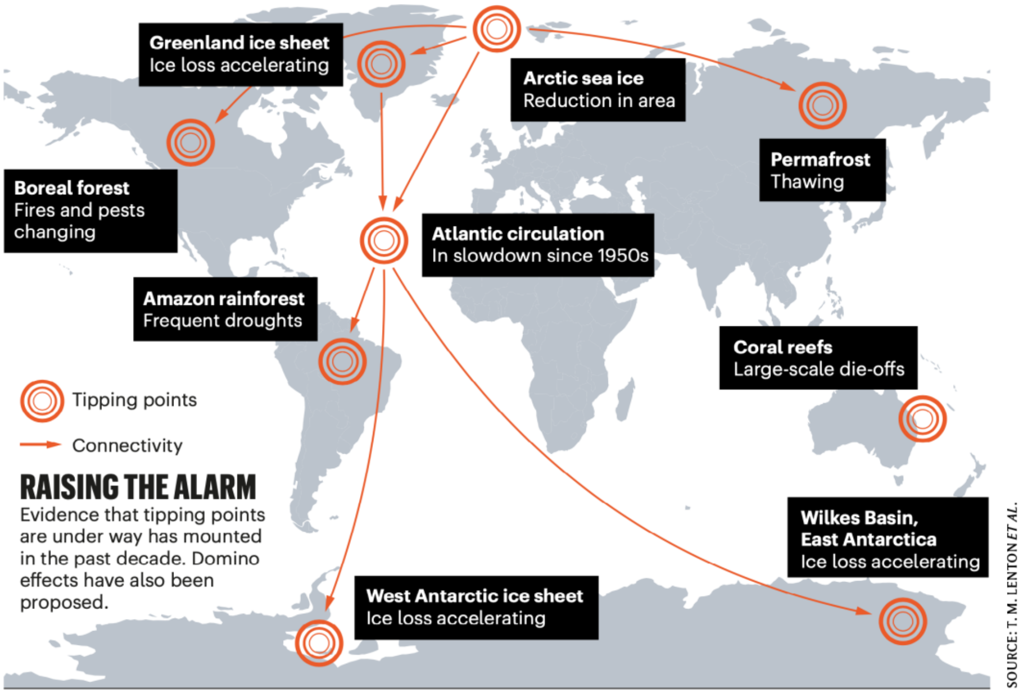

Fig. 7: Tipping elements that are currently changing and their interactions with one another. (Figure from Lenton et al. 2019).

80) **Recent research indicates that tipping point risks are now much higher than earlier estimates**. Over **half of previously identified**[48] **tipping elements are now `active,'** that is, they are moving in the direction that could cause irreversible change (Fig. 7).[49]

81) The recent IPPC AR6 Report states: "**Abrupt responses and tipping points of the climate system, such as strongly increased Antarctic ice sheet melt and forest dieback, cannot be ruled out (*high confidence*).**[50]**"**

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[47] Schellnhuber HJ, Rahmstorf S, Winkelmann R (2016) Why the right climate target was agreed in Paris. *Nature Climate Change*, 6:649-653
[48] Lenton, T.M. et al. (2008) Tipping elements in the Earth's climate system. In PNAS, 105(6), p1786-1793. Accessed from: https://www.pnas.org/content/105/6/1786
[49] Lenton, T.M. et al. (2019) Climate tipping points — too risky to bet against. Nature, 2019; 575 (7784): 592. Accessed at: https://www.nature.com/articles/d41586-019-03595-0
[50] IPCC (2021) Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, accessed at: https://www.ipcc.ch/report/ar6/wg1/#SPM

82) **One of the most significant tipping elements is the Atlantic Meridional Overturning Circulation (AMOC),**[51] a complex of deep and surface currents in the Atlantic Ocean that is responsible for considerable heat exchange between the oceans and the atmosphere, and is part of connected global ocean circulation patterns. **The AMOC appears to be at its weakest point (that is, the circulation and heat exchange is at its slowest) in the past 1000 years**.[52]

83) **Whilst there is *medium confidence* that there will not be an abrupt AMOC collapse before 2100, if such a collapse were to occur, it would *very likely* cause abrupt shifts in regional weather patterns and water cycle**, such as a southward shift in the tropical rain belt, weakening of the African and Asian monsoons and strengthening of Southern Hemisphere monsoons, and drying in Europe.[53]

84) **Continued warming increases the risk** that crossing tipping points will cause subsystems of the Earth to rapidly collapse, one initiating another, to create **a cascade of transformations that result in what has been dubbed a `Hothouse Earth.'** [54] In this future, **average temperatures will rise to match those not seen since the beginning of the Stone Age, millions of years ago, with devastating consequences**. If such a cascade in a domino effect were to occur, the result would be an unrecognisable landscape for current ecosystems and human civilisation.

85) It is **uncertain precisely where this `Hothouse' threshold may lie, but it could be as close as a few decades away, that is, at or just beyond 2°C of warming.**[55]

86) On the basis of the foregoing, **it is reasonable to state that unabated climate change is the greatest threat to the environment and people of NSW.**

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[51] NB: The Gulf Stream is part of AMOC.
[52] Caesar, L., et al. (2021) Current Atlantic Meridional Overturning Circulation weakest in last millennium. Nat. Geosci. 14**,** 118–120 https://doi.org/10.1038/s41561-021-00699-z
[53] IPCC (2021) Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, accessed at: https://www.ipcc.ch/report/ar6/wg1/#SPM
[54] Steffen W et al. (2018) Trajectories of the Earth System in the Anthropocene. Proc. Natl. Acad. Sci. (USA) doi:10.1073/pnas.1810141115 and associated Appendix https://www.pnas.org/content/pnas/115/33/8252.full.pdf
[55] Steffen W et al. (2018) Trajectories of the Earth System in the Anthropocene. Proc. Natl. Acad. Sci. (USA) doi:10.1073/pnas.1810141115 and associated Appendix https://www.pnas.org/content/pnas/115/33/8252.full.pdf

5 Current Impacts of Anthropogenic Climate Change

87) This section describes some of the impacts of climate change that are already occurring. Impacts that can be expected in future, depending on human GHG emissions emitted in the next decades, are discussed in Section 0.

5.1 *The Global Context*

88) Growing GHG concentrations in the atmosphere cause an imbalance in the amount of energy absorbed by the Earth and the amount emitted into space. This imbalance has been growing rapidly. **The Earth's energy imbalance is estimated in mid-2019 to be about 2 to 3 times what it was in mid-2005**.[56]

89) Since the 1980s, each successive decade has been warmer than any preceding decade since 1850.[57] Since 1978, no year has had a global mean temperature below the 1961–1990 average;[58] thus, **no one under the age of 44 has ever experienced a year in which global temperatures were `below normal' by last century's standards.**

90) At the time of writing, the hottest year on record is 2020, at nearly the same temperature as 2016. Despite 2021 being slightly cooler to previous years due to the cooling effect of La Niña, it is still one of the hottest seven years on record.[59] **In fact, the past seven years have been the hottest seven years on record**.[60]

91) Global surface temperature was 1.09°C higher averaged over the period 2011–2020 than in the period 1850–1900, with larger increases over land (1.59°C) than over the ocean

[56] Loeb, N. G., Johnson, G. C., Thorsen, T. J., Lyman, J. M., Rose, F. G., & Kato, S. (2021). Satellite and ocean data reveal marked increase in Earth's heating rate. *Geophysical Research Letters*, *48*, e2021GL093047. Accessed at: https://doi.org/10.1029/2021GL093047

[57] IPCC (2021) Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, accessed at: https://www.ipcc.ch/report/ar6/wg1/#SPM

[58] BOM (2020), Annual Climate Statement 2019, accessed at: http://www.bom.gov.au/climate/current/annual/aus/2019/

[59] WMO (2022) Press Release. https://public.wmo.int/en/media/press-release/2021-one-of-seven-warmest-years-record-wmo-consolidated-data-shows

[60] WMO (2021) State of Global Climate 2021, WMO Provisional Report, accessed at: https://library.wmo.int/index.php?lvl=notice_display&id=21982

(0.88°C).[61] Given that the rate of global warming averages about 0.2°C per decade,[62] **underlying trends in global warming place the world at about 1.2°C above pre-industrial periods in 2022**.

92) **Current effects of climate change worldwide** include:[63] **increased severity of storms and heat waves, species extinction, wildfires, coastal inundation from rising sea levels and increased storm surge, and an increasing risk of crossing so-called 'tipping points' that would accelerate climate change** and greatly intensify its impacts[64], **perhaps irreversibly.**

93) Global effects of climate change are already substantial and costly: [65,66]

a) **Accelerating sea-level rise**, with the observed global rate increasing 25% over the last decade, from 3.04 millimetres per year (mm/yr) during the period 1997–2006 to approximately 4 mm/yr in 2007–2016, driven in part by accelerating land ice melt from Greenland and West Antarctica.

b) **Heat waves,** which were **the deadliest meteorological hazard in the last five years**, affect all continents. Between 2000 and 2016, the number of people exposed to heat waves is estimated to have increased by 125 million.

c) **More extreme wildfires,** including the unprecedented wildfires in 2019 in the Arctic and in the Amazon rainforest, in 2020 and 2021 in California, in 2021 in Canada, and in 2019/20 in Australia.

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[61] IPCC (2021) Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, accessed at: https://www.ipcc.ch/report/ar6/wg1/#SPM

[62] IPCC SR1.5 (2018) Intergovernmental Panel on Climate Change Special Report on Global Warming of 1.5°C. Accessed at: http://ipcc.ch/report/sr15/

[63] IPCC (2014): Summary for policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Field et al. (eds.) Cambridge University Press, pp. 1-32.

[64] Schellnhuber HJ, Rahmstorf S, Winkelmann R (2016) Why the right climate target was agreed in Paris. *Nature Climate Change*, 6:649-653

[65] WMO (2019) United in Science, Report prepared for the UN Climate Action Summit 2019, https://wedocs.unep.org/bitstream/handle/20.500.11822/30023/climsci.pdf

[66] IPCC, SPM (2013) Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, edited by Stocker TF, et al. Cambridge and New York, Cambridge University Press, pp 3-29. https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_SPM_FINAL.pdf

d) **Hotter days and warmer nights** over most land areas. Globally, July 2019 had been listed as the hottest month on record, with July 2020 taking second place.[67] The first-place record has now been eclipsed by July 2021.[68]

e) **Intensification of the hydrological cycle**: increases in the frequency, intensity and amount of heavy precipitation in many areas, and increases in the intensity and duration of drought in other regions.

f) **Ocean acidification**, threatening sea life and destroying entire ecosystems.

g) **Increases in coastal flooding**, caused by more, and more extreme, high sea level events.

94) **In 2020 and 2021 alone** the following extraordinary climate events were recorded,[69,70,71,72] among many others:

a) In both 2020 and 2021, Death Valley in the United States of America (US) reported a temperature of 54.4°C, possibly the **highest temperature ever reliably recorded on Earth**.

b) In South America, **record fires burnt over a quarter of the Pantanal, the world's largest tropical wetlands**, in 2020.

c) **Europe had its warmest year on record**, with 17 countries reporting record average temperatures for 2020.

d) The **highest temperature**, 18.3°C, was **recorded in Antarctica in 2020**.

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[67] NOAA (2020), July 2020 was record hot for N. Hemisphere, 2nd hottest for planet**,** https://www.noaa.gov/news/july-2020-was-record-hot-for-n-hemisphere-2nd-hottest-for-planet

[68] NOAA (2021) https://www.noaa.gov/news/its-official-july-2021-was-earths-hottest-month-on-record

[69] Steffen, W. and Bradshaw, S. (2021) Hitting Home: The Compounding Costs of Climate Inaction, and references cited therein. Climate Council of Australia Ltd. Accessed at: https://www.climatecouncil.org.au/resources/hitting-home-compounding-costs-climate-inaction

[70] Blunden, J. and T. Boyer, eds. (2020) State of the Climate in 2020 in *Bull. Amer. Meteor. Soc.*, 102 (8), Si–S475, https://doi.org/10.1175/2021BAMSStateoftheClimate.1

[71] WMO (2021) State of the Global Climate 2020, Accessed at: https://library.wmo.int/index.php?lvl=notice_display&id=21880#.YOwDJOgzbIV

[72] WMO (2021) State of the Global Climate 2021, WMO Provisional report. Accessed at: https://reliefweb.int/report/world/wmo-provisional-report-state-global-climate-2021

e) In 2021, it rained – rather than snowed – for the first time on record at the peak of the Greenland ice sheet.

f) **A heatwave in Canada** and adjacent parts of the US **pushed temperatures to 49.6°C in 2021 in a village in British Columbia, breaking the previous Canadian national record by 4.6°C**; the town was devastated by fire the next day.

g) In 2020, **Cyclone Gati**, the strongest landfalling cyclone recorded in Somalia, **brought over a year's worth of rain in 24 hours to its city of Bosaso**.

h) In 2020, **wildfires in California displaced 100,000 people from their hom**es. The area burnt in California in 2021 is larger than that burnt in 2020,[73] which itself set records for the state.

i) **In Somalia, floods were associated with the displacement of over one million people** in 2020.

j) **Super Typhoon Goni was the strongest tropical cyclone to make landfall in the historical record and led to the evacuation of almost 1 million people in the Philippines.**

k) In Siberia, an intense, persistent and widespread heat wave broke temperature records, fuelled large fires, and thawed permafrost. The Russian town of Verkhoyansk recorded **a temperature of 38°C in June 2020, likely the highest temperature ever recorded in the Arctic**.

l) Extreme rainfall hit Henan Province of China in 2021. On 20 July, **the city of Zhengzhou received 201.9mm of rainfall in one hour (a Chinese national record)**, 382mm in 6 hours, and 720 mm for the event as a whole, more than its annual average.

m) The on-going megadrought in southwestern North America has been shown to be the driest 22-year period in that area in more than 1200 years.[74]

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[73] https://www.fire.ca.gov/stats-events/

[74] Park Williams, A., Cook, B. I., and Smerdon, J. E. (2022) Rapid Intensification of the emerging southwestern North American megadrought in 2000-2021, in Nature Climate Change, Accessed at: https://www.nature.com/articles/s41558-022-01290-z

95) All extreme weather events, in fact, **all weather events are affected by climate change**, because the environment in which they occur is warmer, moister and contains more energy than used to be the case.[75] The new field of **attribution science is now allowing scientists to quantity the effect of climate change on many extreme events**.

96) Of the 131 studies investigating whether climate change is influencing extreme weather published in the Bulletin of the American Meteorological Society between 2011 and 2016, **65 percent found that the probability of the event occurring was increased due to anthropogenic climate change**. **In the case of some extreme high temperatures, the probability increased by a factor of ten or more**.[76]

97) According to the United Kingdom (UK) Met Office,[77] **human-induced climate change has made the 2018 record-breaking UK summer temperatures about 30 times more likely** than they would naturally occur.

98) More recently it has been found that the **widespread coral bleaching of the Great Barrier Reef during 2016 was made 175 times more likely due to climate change**.[78]

99) The **2020 Siberian heatwave would have been "almost impossible" without human-induced climate change**, as it was made at least 600 times more likely as a result of human-induced climate change.[79]

100) The National Oceanic and Atmospheric Administration (NOAA) of the **United States** tallies weather and climate-related disasters and their associated costs in the US. Their

[75] Trenberth, K. E. (2012), Framing the way to relate climate extremes to climate change, Climate Change, 115(2), 283–290, doi:10.1007/s10584-012-0441-5
[76] WMO (2018) July sees extreme weather with high impacts. Accessed at: https://public.wmo.int/en/media/news/july-sees-extreme-weather-high-impacts
[77] UK Met Office (2018) 2018 UK summer heatwave made thirty times more likely due to climate change. Accessed at https://www.metoffice.gov.uk/about-us/press-office/news/weather-and-climate/2018/2018-uk-summer-heatwave
[78] King A, Karoly D, Black M, Hoegh-Guldberg O, and Perkins-Kirkpatrick S (2016) Great Barrier Reef bleaching would be almost impossible without climate change. The Conversation, April 29, 2016.
[79] Ciavarella, A. et al. (2020) Prolonged Siberian Heat of 2020. *World Weather Attribution.* https://www.worldweatherattribution.org/siberian-heatwave-of-2020-almost-impossible-without-climate-change

most recent work indicates that the numbers and costs of these disasters is rising sharply over time (see Fig.8 below), and specifically that: [80,81]

a) In 2021, there were **20** separate **billion-dollar weather and climate disaster events** across the United States, associated with costs of 145 billion USD. The **average annual cost** of such disasters **over the last five years** (2017-2021) **is 148.4 billion USD**.

b) Adding the 2021 events to the record that began in 1980, the US has sustained **310 weather and climate disasters** where the overall damage costs reached or exceeded $1 billion. The cumulative cost for these 310 events exceeds **2.15 trillion USD**.

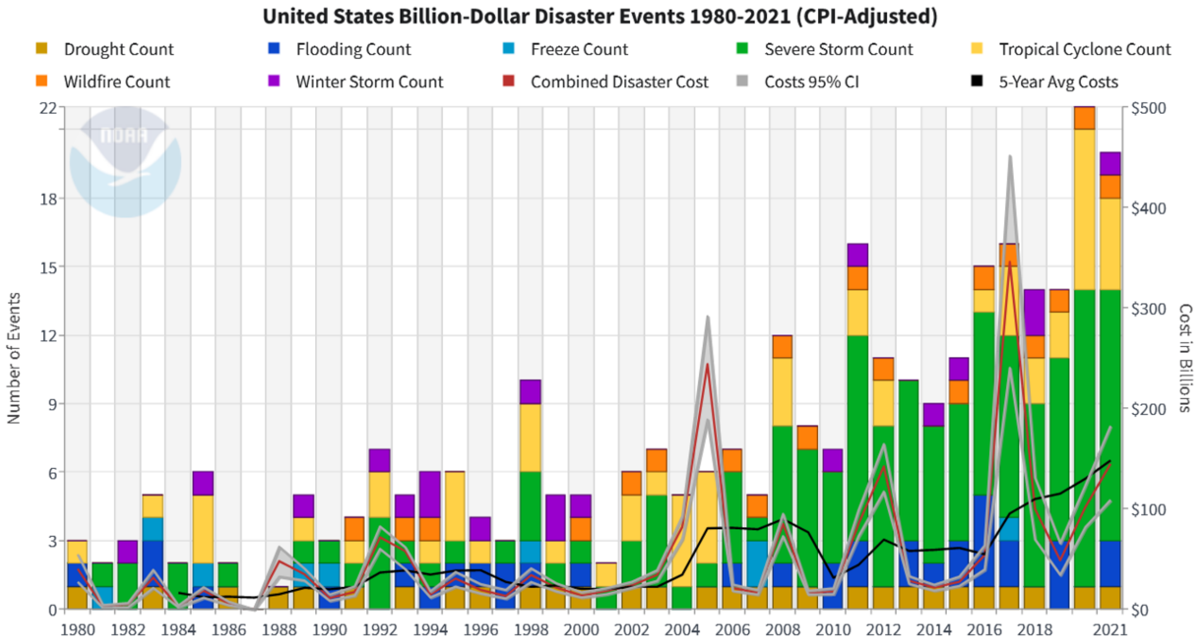

Fig. 8: Over the past 40 years, billion-dollar disasters in the USA have increased sharply in frequency (coloured vertical bars) and total annual costs (lines, with costs given on right-hand vertical axis). Costs have been adjusted for inflation. Figure is from the NOAA.

101) Consequences of more frequent, more costly, and more deadly weather and climate-related disasters include less time to prepare and recover, resources stretched across more than one calamity, and disaster fatigue, especially for first responders. Analysis of data from the US National Oceanic and Atmospheric Administration (NOAA) indicates that the time between billion-dollar disasters has steadily dropped in the US. The average time between such disasters dropped from 82 days in the 1980s to 26 days in the 2010s. **In the**

[80] NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2022). https://www.ncdc.noaa.gov/billions/, DOI: 10.25921/stkw-7w73

[81] NOAA (2022) https://www.climate.gov/news-features/blogs/beyond-data/2021-us-billion-dollar-weather-and-climate-disasters-historical

five years 2016 – 2020, only 18 days separated billion-dollar disasters in the US, on average.[82]

5.2 Australia

102) Australia is witnessing serious climate-related impacts now. According to the recently released sixth report of the IPCC, all areas of Australia have been assessed at high confidence to already be experiencing an increase in heat extremes due to human-caused climate change.[83]

103) Specifically, the Australian Bureau of Meteorology (BOM) and the CSIRO[84,85,86] report that recent climate trends include:

a) Australia has warmed by 1.44 ± 0.24°C since national recording keeping began in 1910. The seven years 2013 – 2019 all rank in the top nine warmest years on record. **Most years in Australia are now warmer than almost any year in the 20th century (2021 was an exception). Australia's hottest year and driest year on record was 2019**.

b) Increased warming, both daytime and night-time, is observed across Australia in all months, sharply increasing the number of extremely warm days. **There were 43 extremely warm days in 2019, more than triple than in any year prior to 2000**.

c) National daily average maximum temperatures have increased dramatically: **33 days exceeded 39°C in 2019, more than the number observed from 1960 to 2018 combined**, which totalled 24 days.

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[82] Climate Central (6 October 2021) Disaster Fatigue, accessed at: https://medialibrary.climatecentral.org/resources/disaster-fatigue

[83] IPCC (2021) Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, accessed at: https://www.ipcc.ch/report/ar6/wg1/#SPM

[84] BOM (2020), Annual Climate Statement 2020, accessed at: http://www.bom.gov.au/climate/current/annual/aus/

[85] CSIRO/BOM (2020), State of the Climate 2020, Commonwealth of Australia. http://www.bom.gov.au/state-of-the-climate

[86] CSIRO/BOM (2021), State of the Climate 2020, Commonwealth of Australia. http://www.bom.gov.au/state-of-the-climate

d) **Very warm day- and night-time temperatures** that occurred only 2% of the time in the past (1960-1989) **now occur five to six times more frequently** (2005-2019). As a result, the frequency of extreme heat events is increasing. (See Fig. 9 below.)[87]

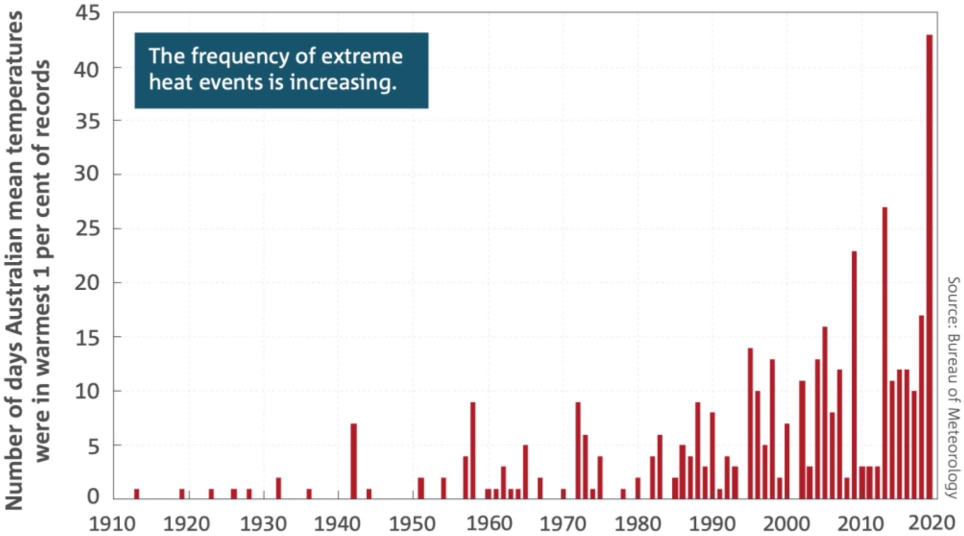

Fig. 9: Number of extreme (top 1%) heat days from 1910 to 2019. Figure from BOM.

e) In December 2019, there were 11 days for which the *national area-averaged* maximum temperature was 40 °C or above[88] (see Fig. 10 below). Only 11 other such days have been recorded since 1910, seven of which occurred in the summer of 2018–19.

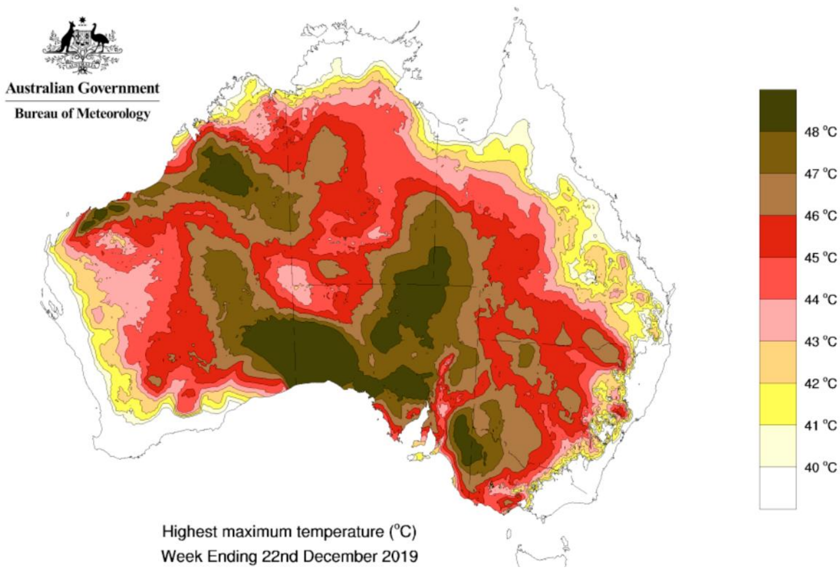

Fig. 10: Highest daily maximum temperature from 16-22 Dec 2019. Figure from BOM.

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[87] CSIRO/BOM (2020), State of the Climate 2020, Commonwealth of Australia. http://www.bom.gov.au/state-of-the-climate

[88] BOM (2019) Special Climate Statement 70b update. Accessed at: http://www.bom.gov.au/climate/current/statements/

f) A **long-term increase in extreme fire weather, and fire-season length, has occurred across large parts of Australia**, with devastating consequences.

g) **Cool-season rainfall has declined in southeast and southwest Australia** over the past 20 years, while rainfall has increased in northern Australia. (See Fig. 11 below.)[89]

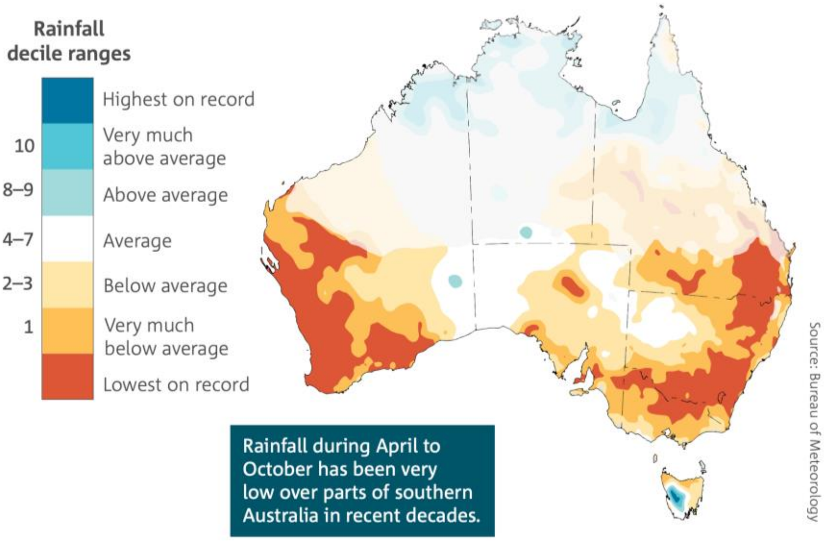

Fig. 11: April to October rainfall deciles for the last 20 years (2000 – 2019) compared to the total entire rainfall record since 1900. Figure from BOM.

h) More of the total annual rainfall in recent decades has come from heavy rain days. **Heavy rainfall events are becoming more intense**.

i) In part due to La Niña effects, rainfall has been above average in 2021. Major flooding occurred in multiple West Gippsland catchments after more than 200 mm of rain fell during the 24 hours in June 2021. **Daily rainfall records were set across a number of stations in Victoria and major flooding resulted in multiple catchments in 2021. It was the wettest November on record for Australia as a whole**, with flooding occurring across large areas of inland NSW and large areas of Queensland.

j) Ocean warming, particularly around southeast Australia and in the Tasman Sea, has contributed to **longer and more frequent marine heatwaves**, depleting kelp forests and sea grasses, increasing disease and bleaching coral reefs.

k) **Increasing acidity of oceans has accelerated, to more than five times faster than that from 1900 to 1960, and 10 times faster than at any time in the past 300 million years**.

[89] CSIRO/BOM (2020), State of the Climate 2020, Commonwealth of Australia. http://www.bom.gov.au/state-of-the-climate

The entire marine ecosystem is affected, with a **significant reduction in coral calcification and growth rates on coral reefs such as the Great Barrier Reef**. The **widespread coral bleaching of the Great Barrier Reef during 2016 was made 175 times more likely due to climate change caused by humans**.[90]

104) A new trend, called **`flash drought' is emerging in Australia**. Flash droughts occur from a very fast reduction in soil moisture, typically caused by a lack of rainfall combined with high temperatures, low humidity, and strong winds. **Flash droughts occur so quickly that adaptation by farmers is difficult**.[91]

105) The cost of extreme weather disasters in Australia has more than doubled since the 1970s, reaching $35 billion for the decade 2010-2019. **Australians are five times more likely to be displaced by a climate-fuelled disaster than someone living in Europe**.[92]

106) **Australia has been rated fourth highest in the G20 for economic losses per unit of GDP incurred from extreme weather events over the last 20 years** (1999-2018).[93]

5.2.1 National Example: Black Summer's climate change fuelled fires in the Here and Now

107) **Australia is the most fire-prone continent on Earth**.[94,95] The accumulation of charcoal (fire residue) in Australia is now higher than at any other time in the last 70,000 years.[96]

108) **The Forest Fire Danger Index (FFDI) indicates the fire danger on a given day** based on daily values for temperature, humidity and wind speed, and a drought factor that represents the influence of recent temperatures and rainfall events on fuel moisture.

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[90] King A, Karoly D, Black M, Hoegh-Guldberg O, and Perkins-Kirkpatrick S (2016) Great Barrier Reef bleaching would be almost impossible without climate change. The Conversation, April 29, 2016.
[91] Steffen, W. and Bradshaw, S. (2021) Hitting Home: The Compounding Costs of Climate Inaction, and references cited therein. Climate Council of Australia Ltd. Accessed at: https://www.climatecouncil.org.au/resources/hitting-home-compounding-costs-climate-inaction
[92] Steffen, W. and Bradshaw, S. (2021) Hitting Home: The Compounding Costs of Climate Inaction, and references cited therein. Climate Council of Australia Ltd. Accessed at: https://www.climatecouncil.org.au/resources/hitting-home-compounding-costs-climate-inaction
[93] Climate Transparency Report (2020) International Climate Transparency Partnership, accessed at: https://www.climate-transparency.org/g20-climate-performance/the-climate-transparency-report-2020
[94] Sharples, J. J. et al. (2016) Natural hazards in Australia: extreme bushfire. Clim. Chang. 139, 85–99
[95] Bradstock, R. A. (2010) A biogeographic model of fire regimes in Australia: current and future implications. Glob. Ecol. Biogeogr. 19, 145–158.
[96] Mooney, S. D. et al. (2011) Late Quaternary fire regimes of Australasia. Quat. Sci. Rev. 30, 28–46.

Extremely dangerous fire weather results in high FFDI values. **An FFDI larger than 50 represents `severe' fire risk that results in a total fire ban. Fire weather drives the chances of a fire starting, its subsequent behaviour, and the difficulty of suppressing it.**

109) **In 2019, the national annual accumulated FFDI was its highest since 1950, when national records began.**[97] Accumulated FFDI reached record high values in areas of all States and Territories in Spring 2019,[98] including essentially all of NSW.

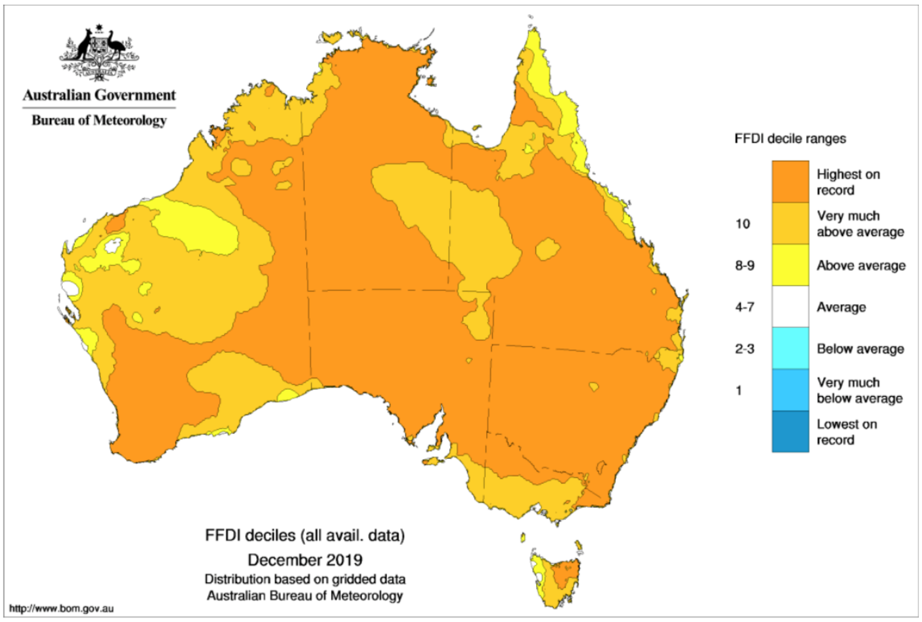

Fig.12: FFDI deciles for December 2019, showing large areas of Australia had highest values on record for that month (dark orange colour). Figure from BOM Climate Statement 73.

110) Those dangerous fire weather conditions continued **into summer of 2019/2020, with December accumulated FFDI values the highest on record across large areas of Australia, and essentially all of NSW** (see Fig. 12 above).[99]

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[97] BOM (2020) Special Climate Statement 73 update, Accessed at: http://www.bom.gov.au/climate/current/statements/

[98] BOM (2020) Special Climate Statement 73 update, Accessed at: http://www.bom.gov.au/climate/current/statements/

[99] BOM (2020) Special Climate Statement 73 update, Accessed at: http://www.bom.gov.au/climate/current/statements/

111) It is not surprising, therefore, that **the Australian 2019/20 bushfires were the worst on record on many measures**.[100,101]

112) **Nearly 80% of all Australians were affected directly or indirectly by the 2019-20 bushfires,**[102] **which has now come to be known as `Black Summer.'**

113) The Black Summer fires resulted in extensive social, environmental and economic impacts. The direct social impacts included the loss of 33 lives[103] and the destruction of over 3,000 houses.[104]

114) The economic costs of Black Summer go beyond the direct impact on gross domestic product (GDP). Nationally, the fire season is expected to break new records for economic costs from bushfires,[105] and **was judged to be Australia's costliest natural disaster up to 2020**.[106]

115) The tourism sector alone is likely to have lost at least $4.5 billion due to effects of the fires.[107] The Australian food system is estimated to have suffered at least $4-5 billion in economic losses due to the Black Summer fires, with only about a third of this recovered

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[100] Hughes, L, Steffen, W, Mullins, G, Dean, A, Weisbrot, E, and Rice, M (2020) *The Summer of Crisis.* Published by the Climate Council of Australia Ltd. Accessed at: https://www.climatecouncil.org.au/resources/summer-of-crisis/ and references cited therein.

[101] Abram, N.J., et al. (2021) Connections of climate change and variability to large and extreme forest fires in southeast Australia, Communications Earth & Environment 2:8, https://doi.org/10.1038/s43247-020-00065-8

[102] Biddle et al. (2020) Exposure and the impact on attitudes of the 2019-20 Australian Bush Fires. ANU Centre for Social Research Methods. Accessed at: https://csrm.cass.anu.edu.au/sites/default/files/docs/2020/2/Exposure_and_impact_on_attitudes_of_the_2019-20_Australian_Bushfires_publication.pdf

[103] Hughes, L, Steffen, W, Mullins, G, Dean, A, Weisbrot, E, and Rice, M (2020) *The Summer of Crisis.* Published by the Climate Council of Australia Ltd. Accessed at: https://www.climatecouncil.org.au/resources/summer-of-crisis/ and references cited therein.

[104] Filkov, A. I., Ngo, T., Matthews, S., Telfer, S. & Penman, T. D. (2020) Impact of Australia's catastrophic 2019/20 bushfire season on communities and environment. Retrospective analysis and current trends. J. Safe. Sci. Resil. 1, 44–56

[105] ANZ Research (2020) Australian bushfires: Impacting GDP. Accessed at: https://bluenotes.anz.com/posts/2020/01/anz-research-australian-bushfires-economic-impact-gdp

[106] Read, P. & Denniss, R. (2020) With costs approaching $100 billion, the fires are Australia's costliest natural disaster. Conversation. Accessed at: https:// theconversation.com/with-costs-approaching-100-billion-the-fires-are- australias-costliest-natural-disaster-129433

[107] AFR (Australian Financial Review) (2020) Tourism loses $4.5b to bush res as overseas visitors cancel. Accessed at: https://www.afr.com/companies/tourism/tourism-loses-4-5b-to-bushfires-as-overseas-visitors-cancel-20200116-p53s0s/

through funding for bushfire recovery. In NSW, over **600,000 hectares of pasture was burnt and nearly 90,000 linear kilometres (km) of agricultural boundary fencing damaged.** [108]

116) Indirect health impacts attributed to smoke exposure include an estimated 417 lives lost and 3,151 hospitalisations.[109] The short-term health costs associated with this smoke exposure is estimated to be $1.95 billion Australia-wide, **with $1.07 billion attributed to NSW losses.**[110] The longer-term premature mortality and economic burden from cumulative effects of smoke exposure will be much higher, by factors estimated to be between two and five.[111]

117) Other long-term health impacts are difficult to quantify, but in the years following previous major fire events ongoing post-traumatic stress disorder and depression have been reported among fire-affected populations.[112] Furthermore, new research points to an under-recognised, potential health threat: microbes that thrive in pyrogenic carbon created by bushfires and can travel hundreds of kilometres once airborne, generating reduced airway conductance and inflammation.[113]

118) Overall, it is estimated that **three billion individual native vertebrates perished in the Black Summer fires**, comprising: 143 million mammals, 2.46 billion reptiles, 180 million birds and 51 million frogs.[114]

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[108] Bishop, J., Bell, T., Huang, C. and Ward, M. (2021) Fire on the Farm: Assessing the Impacts of the 2019-2020 Bushfires on Food and Agriculture in Australia, WWF and University of Sydney. Accessed here: https://www.wwf.org.au/ArticleDocuments/353/WWF Report-Fire on the Farm_converted.pdf.aspx

[109] Borchers Arriagada, N. et al. (2020) Unprecedented smoke-related health burden associated with the 2019–20 bushfires in eastern Australia. Med. J. Aust. 213, 282–283.

[110] Johnston, F.H. et al. (2021) Unprecedented health costs of smoke-related PM2.5 from the 2019-20 Australian megafires, Nature Sustainability, 4, 42-47.https://doi.org/10.1038/s41893-020-00610-5

[111] Johnston, F.H. et al. (2021) Unprecedented health costs of smoke-related PM2.5 from the 2019-20 Australian megafires, Nature Sustainability, 4, 42-47, and Extended Data Fig. 3. https://doi.org/10.1038/s41893-020-00610-5

[112] Bryant, R. A. et al. (2014) Psychological outcomes following the Victorian Black Saturday bushfires. Aust. N. Z. J. Psychiatry 48, 634–643.

[113] Kobziar, L. & Thompson, G.R. (2020) Wildfire smoke, a potential infectious agent: Bacteria and fungi are transported in wildland fire smoke emissions , Science, 18 December 2020, 370, 6523, p 1408-1410. Accessed at: https://science.sciencemag.org/content/370/6523/1408

[114] Van Eeden, L. et al. (2020) Australia's 2019-2020 Bushfires: The Wildlife Toll Interim Report, WWF Australia. Accessed from: https://www.wwf.org.au/news/news/2020/3-billion-animals-impacted-by-australia-bushfire-crisis

119) **In NSW, 37% of the state's rainforests were fire-affected during Black Summer, including over half of the Gondwana Rainforests, an Australia World Heritage Area.[115] These ecosystems are not considered to be resilient to fire**.[116,117] Even in ecological communities that are resilient to fire, such as resprouting eucalypt forests, severe drought had already stressed ecosystems ahead of the Black Summer fires.[118] Recurrent fire damage in some areas may impair the ability of ecosystems to recover.[119]

120) **Temperate broadleaf and mixed (TBLM)** forests in eastern Australia cover about 27 million hectares (Mha); **about half of that forest area lies in NSW**. **In Australia, typically less than 2% of temperate broadleaf forest areas burn annually**, even in extreme fire seasons. The average annual area burnt for most continents is well below 5%, except for Africa and Asia, which have average annual areas burnt of 8-9% for some biomes.[120]

121) Research substantiates that the **Black Summer fires burned a globally unprecedented percentage of any continental forest biome: at least 21% of the Australian Temperate broadleaf and mixed (TBLM) forest biome was burnt in a single season** (Fig. 13).[121]

122) Although the **forest areas lost in Black Summer could, in principle, be recovered by regrowth and replanting**, this will only **take place when the new trees reach full maturity**

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[115] State of NSW Department of Planning Industry and Environment (2020) NSW Fire and the Environment 2019-20 Summary: Biodiversity and landscape data and analyses to understand the effects of fire events. 20pp. (NSW Government, 2020).
[116] Bowman, D. M. J. S. (2000) Australian Rainforests: Islands of Green in a Land of Fire. (Cambridge University Press, 2000).
[117] Dr Patrick Norman (22 January 2021) as quoted in https://inqld.com.au/statewide/2021/01/22/forests-under-fire-black-summer-recovery-still-in-the-wilderness-reports-show/
[118] De Kauwe, M. G. et al. (2020) Identifying areas at risk of drought-induced tree mortality across South-Eastern Australia. Glob. Chang. Biol. 26, 5716–5733.
[119] Lindenmayer, D. B. & Taylor, C. (2020) New spatial analyses of Australian wildfires highlight the need for new fire, resource, and conservation policies. Proc. Natl Acad. Sci. USA 117, 12481.
[120] Boer MM, Resco de Dios V, & Bradstock RA (2020) Unprecedented burn area of Australian mega forest fires, Nature Climate Change. Accessed at: https://www.nature.com/articles/s41558-020-0716-1
[121] M. M. Boer, V. Resco de Dios, R. A. Bradstock, (2020) Unprecedented burn area of Australian mega forest fires. Nat. Clim. Chang. 10, 171–172. doi: 10.1038/s41558- 020-0716-1

in roughly 100 years,[122,123] which is **longer than the time left to reach net zero emissions, for even a 2°C global warming** threshold. Moreover, it is not clear that these forests can fully recover in a climate that continues to warm and dry as a result of climate change.[124]

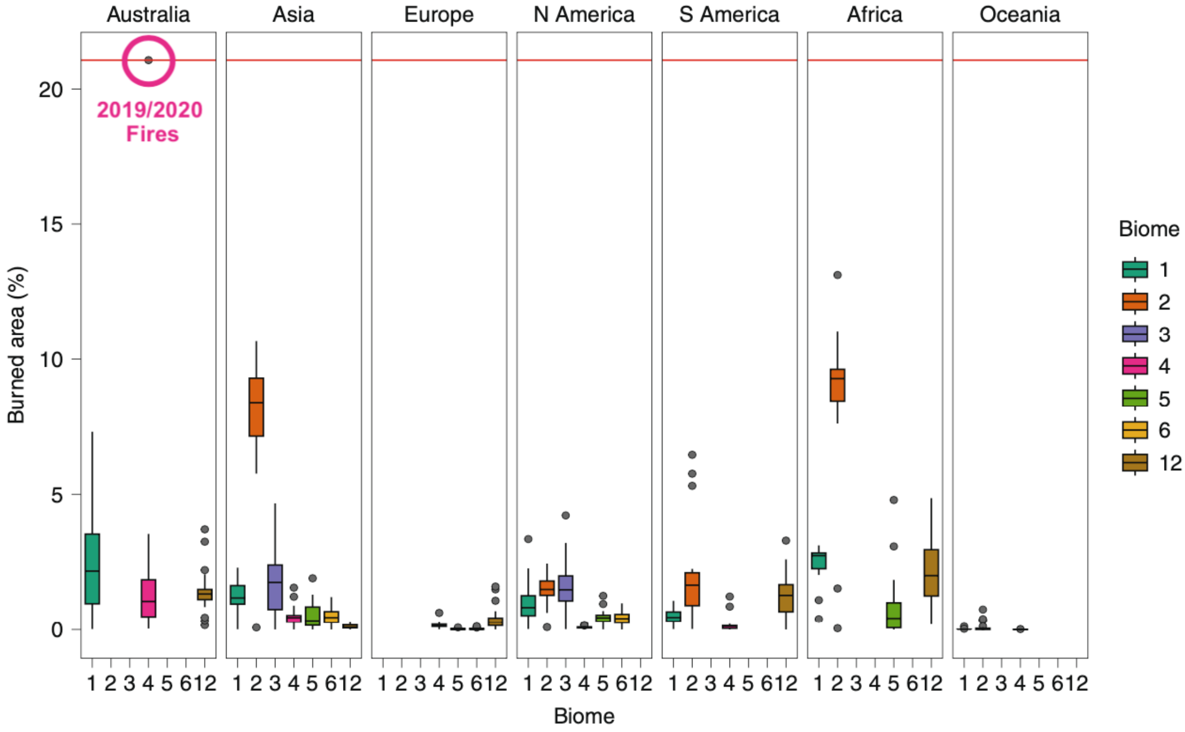

Fig. 13: Annual areas burned for different continental forest types (biomes). Boxplots show the median for each continent. The red horizontal line indicates the burned area of 21% observed for the Australian TBLM forest (biome 4, magenta) resulting from the Black Summer forest fires, far above typical forest areas burnt on any continent. Figure from Boer et al. 2020.

123) Consequently, **local tipping points in some Australian forests may have already been crossed.**[125] The future of these forests will be unlike their historical past, with a **danger that large portions may not be able to regenerate fully before the next catastrophic wildfire**.

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[122] Ngugi MR, Doley D, Cant M & Botkin DB (2015) Growth rates of Eucalyptus and other Australian native tree species derived from seven decades of growth monitoring. Journal of *Forestry Research*, 26 (4) and references therein.

[123] Land for Wildlife. How to Age Trees. Accessed from https://www.lfwseq.org.au/how-to-age-trees/

[124] Science News Magazine (2020) Will Australia's forests bounce back after devastating fires? Posted 11 February 2020. Accessed at: https://www.sciencenews.org/article/australia-forest-ecosystem-bounce-back-after-devastating-fires

[125] Steffen, W. and Bradshaw, S. (2021) Hitting Home: The Compounding Costs of Climate Inaction, and references cited therein. Climate Council of Australia Ltd. Accessed at: https://www.climatecouncil.org.au/resources/hitting-home-compounding-costs-climate-inaction

124) Australia's Black Summer is consistent with previous scientific assessments dating back at least 30 years that human-caused climate warming will increase the duration, frequency and intensity of forest fires in southeast Australia.[126,127,128]

125) **Since the mid-twentieth century, the clear trend is towards more dangerous forest fire weather in Australia, and increasingly long fire seasons that start earlier**.[129,130,131] These trends are strengthening. **Key climate change drivers of fire risk,** particularly in southeast Australia, **are becoming stronger**.[132,133]

126) A recent study, using satellite observations with other constraints, shows that the **Black Summer** fires released 715 million tonnes (Mt) of carbon dioxide (range 517 – 867 Mt) into the atmosphere in the three months between November 2019 and January 2020.[134] This is about twice the amount of CO_2 released by Australia in 2019 from other sources.[135] Because not all of these forests are expected to obtain full regrowth before the next large scale fire, not all of this CO_2 is likely to be re-sequestered; some will

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[126] Beer, T., Gill, A. M. & Moore, P. H. R. (1988) in Greenhouse: Planning for Climatic Change (ed. Pearman, G. I.) 421–427 (CSIRO Publishing)

[127] Reisinger, A. et al. (2014) in Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. (eds V. R. Barros et al.) Ch. 25, 1371–1438 (Cambridge University Press, 2014).

[128] Hennessy, K. et al. (2007) Australia and New Zealand in Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (eds Parry, M. L. et al.) 507–540 (Cambridge University Press, 2007).

[129] Harris, S. & Lucas, C. (2019) Understanding the variability of Australian fire weather between 1973 and 2017. PLoS ONE 14, e0222328.

[130] Dowdy, A. J. (2018) Climatological variability of fire weather in Australia. J. Appl. Meteorol. Climatol. 57, 221–234.

[131] Abram, N.J., et al. (2021) Connections of climate change and variability to large and extreme forest fires in southeast Australia, Communications Earth & Environment 2:8, https://doi.org/10.1038/s43247-020-00065-8

[132] Matthews, S., Sullivan, A. L., Watson, P., & Williams, R. J. (2012) Climate change, fuel and fire behaviour in a eucalypt forest. Global Change Biology, 18(10), 3212-3223. doi:10.1111/j.1365-2486.2012.02768.x

[133] Pitman, A. J., Narisma, G. T., & McAneney, J. (2007) The impact of climate change on the risk of forest and grassland fires in Australia. Climatic Change, 84(3), 383-401. doi:10.1007/s10584-007-9243-6

[134] Van der Velde, I.R. et al. (2021) Vast CO2 relrease from Australian fires in 2019-2020 constrained by satellite. Nature, 597 (7876): 366-369. doi:10.1038/s41586-021-03712-y

[135] National Greenhouse Gas Inventory, maintained by the Australian Government's Department of the Industry, Science, Energy and Resources. Accessed at http://ageis.climatechange.gov.au/

permanently contribute to growing atmospheric CO_2 concentrations.[136] This is an example of how climate change can be self-reinforcing, through what is known scientifically as `carbon feedback.'

5.3 New South Wales and the Narrabri Surrounds

127) Most of the **climate change impacts experienced by Australia are being felt in NSW**.[137,138,139,140] What follows are just some of the current consequences for NSW over the past few years:

a) **NSW had its hottest and driest year in 2019, with a mean temperature 1.95°C above average and 0.27°C warmer than the previous warmest year, 2018**. Days were especially warm in 2019, with the NSW mean maximum temperature at a record high of 2.44°C above average.

b) **Penrith Lakes recorded 48.9°C on 4 January 2020, the highest temperature ever recorded in the Sydney basin**. Many sites in metropolitan Sydney exceeded 47°C. Such temperatures are dangerously hot, and place extreme thermal stress on humans and the environment. Fig. 14 shows how extreme high temperatures have been in NSW over the past 20 years.

c) NSW not only experienced extreme heat in December 2019 and January 2020, but also increased bushfire activity and poor air quality in Sydney. **NSW had its highest accumulated FFDI for December in 2019**. FFDI records date back to 1950.

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[136] Van der Velde, I.R. et al. (2021) Vast CO2 release from Australian fires in 2019-2020 constrained by satellite. Nature, 597 (7876): 366-369. doi:10.1038/s41586-021-03712-y

[137] BOM (2019), Annual Climate Statement 2019, NSW, accessed at: http://www.bom.gov.au/climate/current/annual/nsw/archive/2019.summary.shtml

[138] BOM (2020), Annual Climate Statement 2020, NSW, accessed at: http://www.bom.gov.au/climate/current/annual/nsw/archive/2020.summary.shtml

[139] BOM (2020) Special Climate Statement 73 update, Accessed at: http://www.bom.gov.au/climate/current/statements/

[140] BOM (2021) Annual Climate Statement 2021, NSW, accessed at: http://www.bom.gov.au/climate/current/annual/nsw/archive/2021.summary.shtml

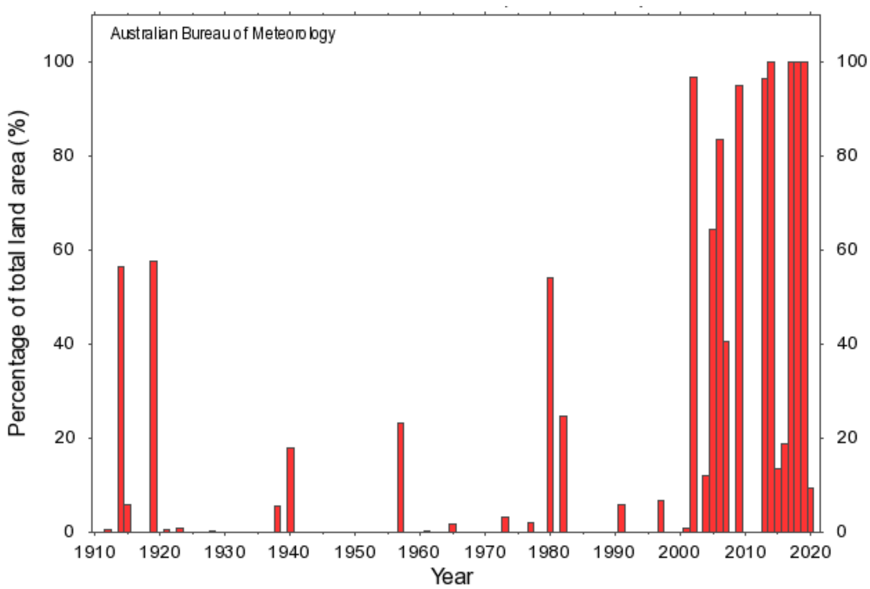

Fig. 14: The percentage of NSW area (from 0 to 100%) that experienced a maximum annual temperature in the top 10% of all records. These data from BOM cover years 1910 through 2021.

d) Total rainfall for NSW was the lowest on record in 2019 at 55% below average; well below the previous driest year of 1944.

e) **Narrabri is located in the northern Murray-Darling Basin**, a region for which the 34 months **in the period January 2017 to October 2019 recorded rainfall that was the lowest on record** by a substantial margin, **breaking records originally set during the Federation Drought in 1900–1902**.

f) The extent and timing of the dry conditions meant that **agriculture was particularly affected with the top 100 cm of soil at record moisture lows at** many locations (see Fig. 15).[141] Root zone soil moisture for October 2019 was below average to very much below average across most of the Murray–Darling Basin, with some areas in the centre and north of the Basin having the lowest soil moisture levels for October on record since 1910. The **unprecedented conditions of inland NSW in mid-2019 correspond to what meteorologists are now calling a 'flash drought,'** conditions that were similar to those along the east coast in the months bridging 2017 and 2018.[142]

[141] BOM (2019) Special Climate Statement 70 update, Accessed at: http://www.bom.gov.au/climate/current/statements/

[142] Steffen, W. and Bradshaw, S. (2021) Hitting Home: The Compounding Costs of Climate Inaction, and references cited therein. Climate Council of Australia Ltd. Accessed at: https://www.climatecouncil.org.au/resources/hitting-home-compounding-costs-climate-inaction

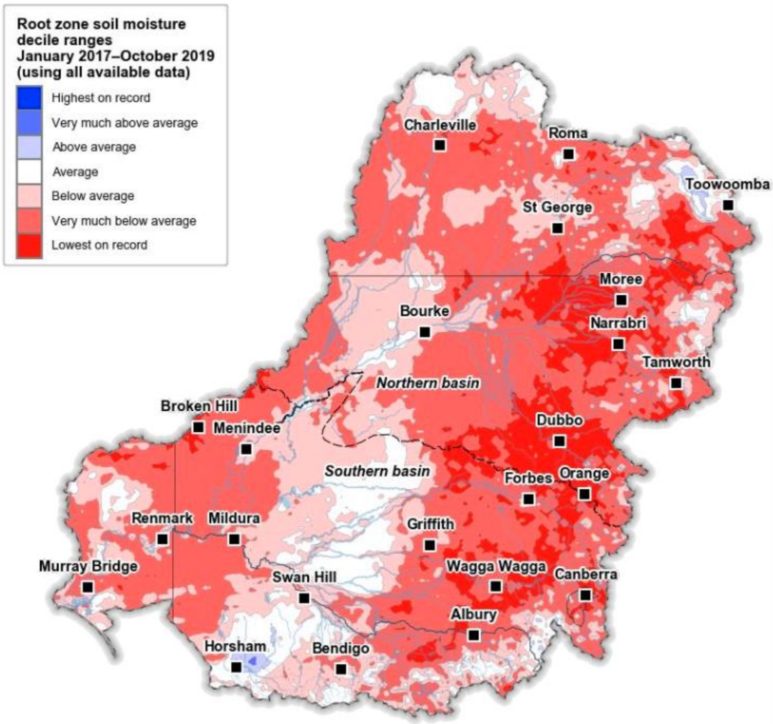

Fig. 15: Root zone soil moisture in top 100cm of soil over the northern Murray-Darling Basin in interior NSW for period Jan 2017 – Oct 2019. Note that Narrabri sits in the most severely impacted region.

g) **Switching abruptly from record low rainfall in 2019 to heavy rain records in 2020**, many **NSW sites experienced their highest annual rainfall on record or their highest for at least 20 years**. In early 2020, coastal regions had especially heavy rain, when many sites had their highest daily rainfall on record.

h) Assisted by La Niña conditions, **heavy rainfall continued into 2021**, as coastal NSW, including Sydney, experienced multiple days of heavy rainfall. **The week ending 24 March 2021 was the wettest week for the region since national daily records began in 1900**.[143]

i) While **the March 2021 rainfall** allowed some recovery of groundwater levels in the northern Murray-Darling Basin, it **came at the expense of flooding, and was followed by more flooding in November 2021, which was NSW's wettest November on record. Some areas experienced their worst flooding in 30 years**. **Narrabri Airport broke a 20-year record for maximum annual rainfall in 2021.**[144]

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[143] BOM (2021) Special Climate Statement 74, Accessed at: http://www.bom.gov.au/climate/current/statements/
[144] BOM (2021) Annual Climate Statement 2021, NSW, accessed at: http://www.bom.gov.au/climate/current/annual/nsw/archive/2021.summary.shtml

128) **Narrabri sits in a portion of NSW known as the North West**. According to the CSIRO and BOM,[145] the past 30 years have not shown a long-term trend in the amount of annual rainfall, though **winter rainfall has decreased somewhat and not been reliable (meaning that there are great swings in winter rainfall from year to year.)**

129) **The North West of NSW is experiencing more very hot days than in the past,** visible in the increase in the number of days above 38°C, as shown in Fig. 16 which displays this rising trend for Tamworth. Instances of *consecutive* days above 38°C have also been more frequent in the past 30 years. Twice in 2018 and once in 2019, Tamworth experienced periods of six or more days in a row above 38°C.[146]

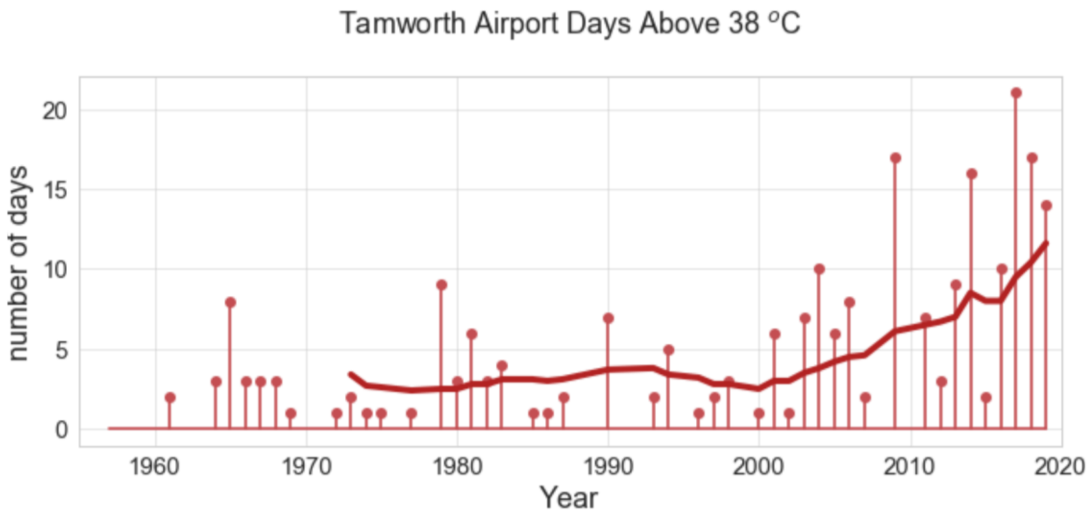

Fig. 16: The number of days above 38°C registered at Tamworth (red bars), with the 10-year running average shown as the bold red line, over the past 60 years. Figure from BoM and CSIRO Climate Guide.

130) **Temperatures of 38°C or more – above the internal core body temperature of humans – are particularly dangerous for human health.** In the period 1991–2018, 37% of warm-season heat-related deaths can be attributed to anthropogenic climate change.[147]

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[145] BOM and CSIRO (2019) North West NSW Regional Weather and Climate Guide, accessed at: http://www.bom.gov.au/climate/climate-guides/

[146] BOM and CSIRO (2019) North West NSW Regional Weather and Climate Guide, accessed at: http://www.bom.gov.au/climate/climate-guides/

[147] Vicedo-Cabrera, A.M. et al. (2021) The burden of heat-related mortality attributable to recent human-induced climate change. Nature Climate Change, 11, 492-500. Accessed at: https://www.nature.com/articles/s41558-021-01058-x

131) The chart of `heat index' (or `apparent temperature') shown in Fig. 17 shows that the index rises sharply as air temperature and relative humidity climb, as does the danger to human health, as indicated by the colour coding and the associated text.[148]

Temperature (°C)

Relative Humidity (%)	26.7	27.8	28.9	30.0	31.1	32.2	33.3	34.4	35.6	36.7	37.8	38.9	40.0	41.1	42.2	43.3
40	26.7	27.2	28.3	29.4	31.1	32.8	34.4	36.1	38.3	40.6	42.8	45.6	48.3	51.1	54.4	57.8
45	26.7	27.8	28.9	30.6	31.7	33.9	35.6	37.8	40.0	42.8	45.6	48.3	51.1	54.4	58.3	
50	27.2	28.3	29.4	31.1	32.8	35.0	37.2	39.4	42.2	45.0	47.8	51.1	55.0	58.3		
55	27.2	28.9	30.0	31.7	33.9	36.1	38.3	41.1	44.4	47.2	51.1	54.4	58.3			
60	27.8	28.9	31.1	32.8	35.0	37.8	40.6	43.3	46.7	50.6	54.4	58.3				
65	27.8	29.4	31.7	33.9	36.7	39.4	42.2	45.6	49.4	53.3	57.8					
70	28.3	30.0	32.2	35.0	37.8	40.6	44.4	48.3	52.2	56.7						
75	28.9	31.1	33.3	36.1	39.4	42.8	46.7	51.1	55.6							
80	28.9	31.7	34.4	37.8	41.1	45.0	49.4	53.9								
85	29.4	32.2	35.6	38.9	43.3	47.2	52.2	57.2								
90	30.0	32.8	36.7	40.6	45.0	50.0	55.0									
95	30.0	33.9	37.8	42.2	47.2	52.8										
100	30.6	35.0	39.4	44.4	49.4	55.6										

Classification	Effect on the Body
Caution:	Fatigue possible with prolonged exposure and/or physical activity
Extreme Caution:	Heat stroke, heat cramps, or heat exhaustion possible with prolonged exposure and/or physical activity
Danger:	Heat cramps or heat exhaustion likely, and heat stroke possible with prolonged exposure and/or physical activity
Extreme Danger:	Heat stroke highly likely

Fig. 17: Heat index for different temperatures and relative humidity. The table values are for shaded areas. If one is exposed to direct sunlight, the heat index value can be increased by up to 8°C.

132) NSW Health Department information on heat-related illnesses,[149] including dehydration, heat rash, heat exhaustion, heat cramps and heat stroke, states: "When the air is hotter than around 35°C, the body can only lose heat through sweating [which] can be impaired by humidity . . ." **Heat stroke occurs when the core temperature of the human body rises, and can cause shock, arrhythmia, altered mental state, convulsions, unconsciousness, and possible death.**

133) **With continued global warming, Sydney is considered the most vulnerable of all the six capital Australian cities, as it currently experiences at least 6.4 additional deaths on days with temperatures in excess of (only) 30°C.**[150]

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[148]Figure after that published by the US National Weather Service, NOAA, What is the heat index? Accessed at: https://www.weather.gov/ama/heatindex

[149] https://www.health.nsw.gov.au/environment/beattheheat/Pages/information-for-health-professionals.aspx

[150] Herold, N. (2018) Australian climate extremes in the 21st century according to a regional climate model ensemble: Implications for health and agriculture, Weather and Climate Extremes, 20, 54–68, https://doi.org/10.1016/j.wace.2018.01.001

6 Future Impacts of Climate Change

134) At its simplest level, **future climate change can be projected on the basis of different scenarios for future human GHG emission trajectories**.

135) Other drivers of future climate change include **the speed with which the planet responds to feedbacks in the Earth System**, and how these interact with one another, possibly cascading to create a planetary tipping point. (These are discussed in subsections 4.7 and 4.8 of this Report.)

136) A brief overview of possible emission trajectories and their consequences for global warming levels is presented in subsection 6.1, making comparisons with the warming target of the UNFCCC **Paris Agreement,**[151] which **commits signatories to "holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C."** Australia is a signatory to the Paris Agreement. Current emissions trajectories for the world, Australia and New South Wales are discussed in more detail in Section 173).

137) Possible climate futures for the world, Australia and NSW are sketched below in subsections 6.2, 6.3, and 6.4, respectively. Which of these futures is realised depends on the trajectory of human GHG emissions.

6.1 Why emissions trajectories matter

138) Projections of how the climate will evolve into the future depend on the direction and speed with which global emissions evolve. **If the trend of rising emissions is continued**, the world will be on a pathway similar to the scenarios[152] labelled RCP6.0 and RCP8.5 by the fifth Assessment Report (AR5) of the IPCC,[153] based on extrapolation of observed

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[151] UN (2015), Paris Agreement, Accessed from https://unfccc.int/sites/default/files/english_paris_agreement.pdf

[152] NB: "RCP" is Representative Concentration Pathway, which is a scenario for the concentration of greenhouse gases in the atmosphere. The numbers refer to the 'radiative forcing' for a scenario, in Watts per square metre.

[153] Collins, M. et al. (2013) Long-term climate change: Projections, commitments and irreversibility, in Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, edited by Stocker et al. Cambridge University Press, pp. 1029-1136.

emissions trends,[154] and consistent with recent analyses.[155] In this case, **global warming could be 3—4°C above pre-industrial times in just 80 years**.

139) The **recently released sixth IPCC Assessment Report (AR6)** from Working Group 1,[156] expands this older work, **using improved climate modelling constrained by previous climate responses to consider five illustrative scenarios for how human emissions may proceed from now until the year 2100**. Those scenarios are labelled: SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5, in order of lowest to highest emissions.[157] They are similar to, but not identical to the RCP-labelled scenarios of the fifth IPCC assessment. The global warming consequences of each of these five emissions scenarios are shown in Fig. 18 below.

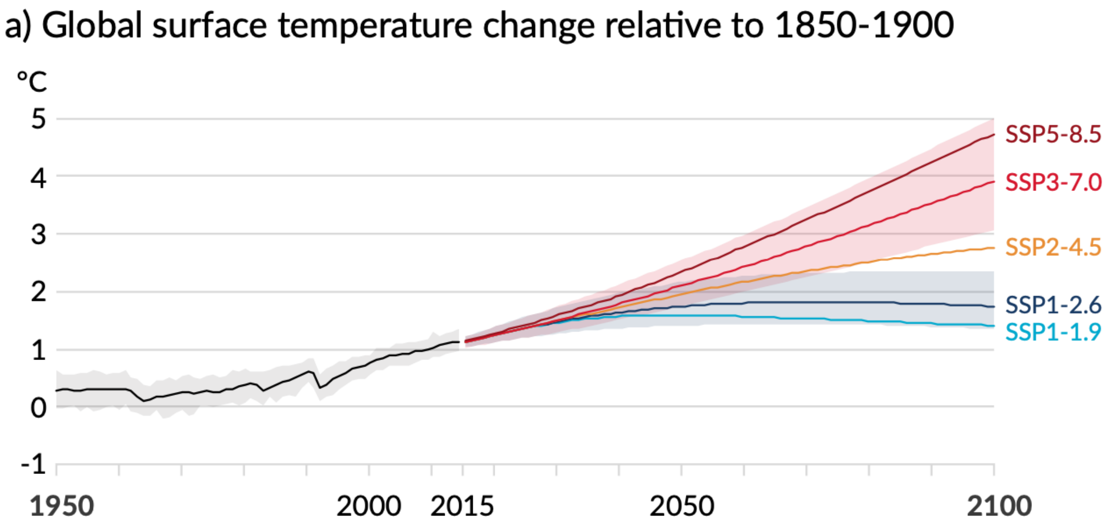

Fig 18: Projections for each of the five AR6 emission scenarios are shown in colour. The black curve indicates past warming. Shaded regions show the `very likely' ranges for the SSP1-2.6 and the SSP3-7.0 scenarios. Figure reproduced from the IPCC ARC WGI Summary for Policy Makers, Fig. SPM.8.

140) ***All* scenarios considered in AR6 WG1, including the lowest emission trajectory (SSP1-1.9), are more likely than not to reach or exceed 1.5°C of warming this century.** The best estimate for the lowest emission scenario (SSP1-1.9) is that 1.5°C will be reached before 2040, likely peaking at 1.6°C around mid-century, and that warming will then drop slightly

[154] Le Quéré, C et al. (2018) Global Carbon Budget 2018, Earth Syst. Sci. Data, 10, 2141–2194, https://doi.org/10.5194/essd-10-2141-2018
[155] Climate Action Tracker (2020) https://climateactiontracker.org/global/cat-thermometer/
[156] https://www.ipcc.ch/report/ar6/wg1/#FullReport
[157] IPCC (2021) Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, accessed at: https://www.ipcc.ch/report/ar6/wg1/#SPM

to 1.4°C at century's end.[158] **This means that humanity has likely lost the chance to hold warming strictly below 1.5C, the lowest of the Paris Agreement targets, but may still have the possibility of returning global temperatures to that value in 80 years' time.**

141) Indeed, due to natural fluctuations, the world may soon experience years in which the global average temperature exceeds 1.5°C of warming. Work led by the UK Met Office shows **there is a 40% chance that the world will see global average 1.5°C warming (at least temporarily) sometime before 2025.**[159]

142) **In order to hold global warming *well-below* 2°C, the upper of the Paris Agreement targets**, human emissions trajectories must be more closely aligned with the SSP1-1.9 or SSP1-2.6 scenarios than the other three scenarios, requiring "**deep reductions in CO_2 and other greenhouse gas emissions occur in the coming decades**,"[160] according to the AR6 IPCC report.

143) The **higher emission scenarios SSP2-4.5, SSP3-7.0 and SSP5-8.5 all carry a significant of risk of global warming of at least 3°C by 2100, with SSP3-7.0 and SSP5-8.5 very likely to reach 3°C to 4°C by then, and continue to rise thereafter**.

144) The subsections that follow describe possible climate futures in a world experiencing different levels of global warming, including 1.5°C (which is now essentially inevitable), 2°C, 3°C and higher above pre-industrial times. **What separates these possible futures is the trajectory of human GHG emissions, particularly in the next decade**.

6.2 Possible World Futures at Different Levels of Global Warming

145) **Climate impacts are hitting harder and sooner than previous scientific assessments have expected.** Over two decades, the IPCC has published a series of science-based risk assessments for people, ecosystems and economies worldwide. **A comparison of these**

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[158] IPCC (2021) Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Table SPM.1, accessed at: https://www.ipcc.ch/report/ar6/wg1/#SPM
[159] WMO 2020, Global Annual to Decadal Climate Update: Target years 2021, and 2021-2025. Accessed at: https://hadleyserver.metoffice.gov.uk/wmolc/ on 17 December 2021.
[160] IPCC (2021) Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, accessed at: https://www.ipcc.ch/report/ar6/wg1/#SPM

"Reasons for Concern" (see Fig. 19 below based on the WMO 2019 report)[161] **shows that the level of risk has increased with each subsequent analysis from 2001 to 2018**. More recent IPCC reports indicate higher risks (redder colours) than did previous reports for the same average global warming.

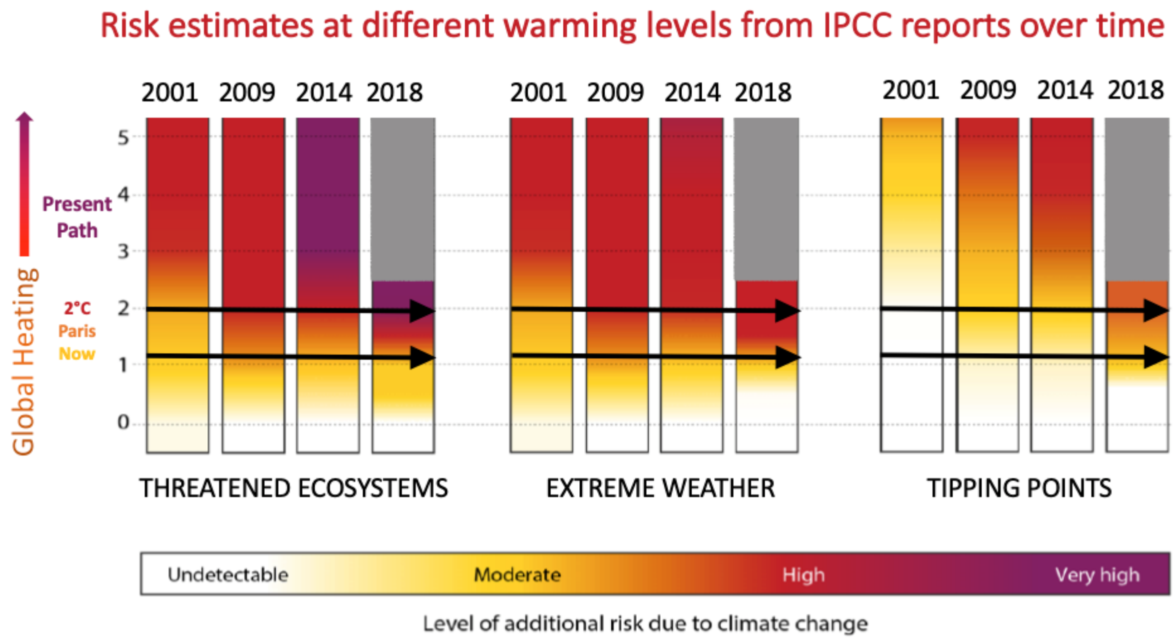

Fig. 19: As temperature (above pre-industrial time) climbs upward, climate risks increase (shown by deeper, dark colours). Indicated are the present (marked as "now"), the Paris Agreement Range, a 2°C scenario, and the current trajectory leading to 3°C to 4°C of global heating. Results from more recent IPCC reports (arrows moving left to right) indicate higher risks than did earlier reports at the same temperature. (Areas marked in grey were not formally assessed by the 2018 IPCC Special Report on 1.5°C of warming.)

146) The conclusion is clear**: the more we know, the more we realise how dangerous even a small amount of warming can be**.

147) We now know that the Earth will experience 1.5°C of warming (see paragraph 140), and so it is clear that the world faces still greater risks from climate change.

148) **The Paris Agreement range of 1.5°C to well below 2.0°C is not 'safe' (though it is much safer than higher temperatures).** Within this range of warming, ecosystems are at high to very high risk, there is a high risk of extreme global weather events, and a moderate risk of large-scale singular events that could lead to climatic tipping points, as Fig. 20 shows.

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[161] WMO 2019, United in Science, Report prepared for the UN Climate Action Summit 2019, https://wedocs.unep.org/bitstream/handle/20.500.11822/30023/climsci.pdf

149) Recent research indicates that **even under 1.5°C of warming, thousands of global locations will experience what are now considered `once-in-100-years extreme-sea-level events'** ***at least once a year*** **by 2100**.[162]

150) **At 2°C warming, 99% of the world's coral reefs, including the Great Barrier Reef, are very likely to be eliminated**, and **crisis upon crisis will compound for the world's most vulnerable people.**[163]

151) Specifically, **if emissions do not come down drastically before 2030, the world will be on a path to 2°C of warming or more**, and **by 2040 some 3.9 billion people are likely to experience major heatwaves, 12 times more than the historic average.** By the 2030s, 400 million people globally each year are likely to be exposed to temperatures exceeding the workability threshold. Also, **by the 2030s, the number of people on the planet exposed to heat stress exceeding the survivability threshold is likely to surpass 10 million a year.**[164]

152) Although agriculture will need to produce almost 50% more food by 2050, yields could decline by 30% and **by 2040, the average proportion of global cropland affected by severe drought will likely rise to 32% a year, more than three times the historic average**.[165]

153) **At 3°C–4°C of warming** above pre-industrial temperatures (a possible consequence of continuing on our current path), today's world would be nearly unrecognisable, with high to very high risk that:[166]

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[162] Tebaldi, C. et al. (2021) Extreme sea levels at different global warming levels. In Nature Climate Change, 11, 746-751, https://doi.org/10.1038/s41558-021-01127-1

[163] IPCC SR1.5 (2018) Intergovernmental Panel on Climate Change Special Report on Global Warming of 1.5°C. Accessed at: http://ipcc.ch/report/sr15/

[164] Quiggin, D, De Meyer, K, Hubble-Rose, L, and Froggatt, A. (2021) Climate change risk assessment 2021, Royal Institute of International Affairs, Chatham House. Accessed at: https://www.chathamhouse.org/2021/09/climate-change-risk-assessment-2021

[165] Quiggin, D, De Meyer, K, Hubble-Rose, L, and Froggatt, A. (2021) Climate change risk assessment 2021, Royal Institute of International Affairs, Chatham House. Accessed at: https://www.chathamhouse.org/2021/09/climate-change-risk-assessment-2021

[166] IPCC (2014): Summary for policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Field et al. (eds.) Cambridge University Press, pp. 1-32.

a) **Most of the world's ecosystems are heavily damaged or destroyed**;

b) **Extreme weather events are far more severe and frequent** than today;

c) **Large areas of the world become uninhabitable. Migration and conflict escalate**;

d) **Aggregated global impacts significantly damage the entire global economy**; and

e) A **moderately high risk** that a cascade of tipping points in the climate system drives the **Earth system into a state not seen for millions of years**, irrespective of humanity's late attempts to reduce emissions.[167]

154) **Over the next 2000 years, global mean sea level will rise by about 2 – 3m if warming is limited to 1.5°C, 2 – 6m if limited to 2°C, and 19 – 22m with 5°C of warming, and it will continue to rise over subsequent millennia** (*low confidence*).[168]

155) **At 5°C of warming or above,** which is possible in the highest emissions scenario SSP5-8.5 by the end of the century (see Fig. 19), **it has been estimated[169] that a mass extinction would occur comparable to the `big five' mass extinctions over the past 450 million years that resulted in extinction of 75% of all marine species.**

6.3 Possible Australian Futures

156) **Regardless of emission scenarios**, the CSIRO and BOM[170] report that **Australia will certainly experience more extreme climate effects**, including:

a) Further warming, with more extremely hot days and fewer extremely cool days.

b) A **decrease in cool-season rainfall** across many regions of the south and east of Australia, with more time spent in drought.

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[167] Steffen W et al. (2018) Trajectories of the Earth System in the Anthropocene. *Proc. Natl. Acad. Sci. (USA)* doi:10.1073/pnas.1810141115 and associated Appendix https://www.pnas.org/content/pnas/115/33/8252.full.pdf

[168] IPCC (2021) Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, accessed at: https://www.ipcc.ch/report/ar6/wg1/#SPM

[169] Song, H., Kemp, D.B., Tian, L., Chu, D, Song, H., and Dai, X. (2021) Thresholds of temperature change for mass extinctions. Nature Communications 12: 4694, https://www.nature.com/articles/s41467-021-25019-2

[170] CSIRO/BOM (2020) State of the Climate 2020, Commonwealth of Australia. http://www.bom.gov.au/state-of-the-climate/

c) A longer fire season for the south and east and an **increase in the number of dangerous fire weather days**.

d) **More intense short-duration heavy rainfall events** throughout the country.

e) Fewer tropical cyclones, a greater proportion of which will be of high intensity.

f) **More frequent, extensive, intense and longer-lasting marine heat waves**, increasing risk of frequent and severe bleaching of the Ningaloo and Great Barrier Reefs.

g) Oceans around Australia will continue to warm, rise and become more acidic.

h) **Ongoing sea level rise,** with recent research on ice sheet melting revealing that sea level rise could be higher than previously assessed.

Specifically, the CSIRO/BOM 2020 report states that:

i) **For most of the Australian coast, extreme sea levels that had a probability of occurring *once in a hundred years* are projected to become an *annual event* by the end of this century with lower emissions, and by mid-century for higher emissions**.

j) **The year 2019 was Australia's hottest year on record. That temperature is expected to be an *average* year when global mean warming reaches 1.5 °C above the pre-industrial baseline period of 1850–1900**.

k) **While the current decade is warmer than any other decade over the last century, it is also likely to be the *coolest* decade for the century ahead**.

157) Australian continental temperatures are observed to be about 1.4 times greater than global average temperatures[171]. Thus, global warming between 1.5°C and 2°C above 1850-1900 levels translates into rises of 2.1°C and 2.8°C for Australia. (See Fig. 20 below.)[172]

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[171] In general, the surface of land masses warm more quickly than the ocean due to differences in reflectivity and heat capacity. The poles or land near the poles warm more quickly due to ice loss which would otherwise have a cooling effect. Other factors are also at play. See: e.g., https://climate.mit.edu/ask-mit/which-parts-planet-are-warming-fastest-and-why

[172] CSIRO/BOM (2020) State of the Climate 2020, Commonwealth of Australia. http://www.bom.gov.au/state-of-the-climate/

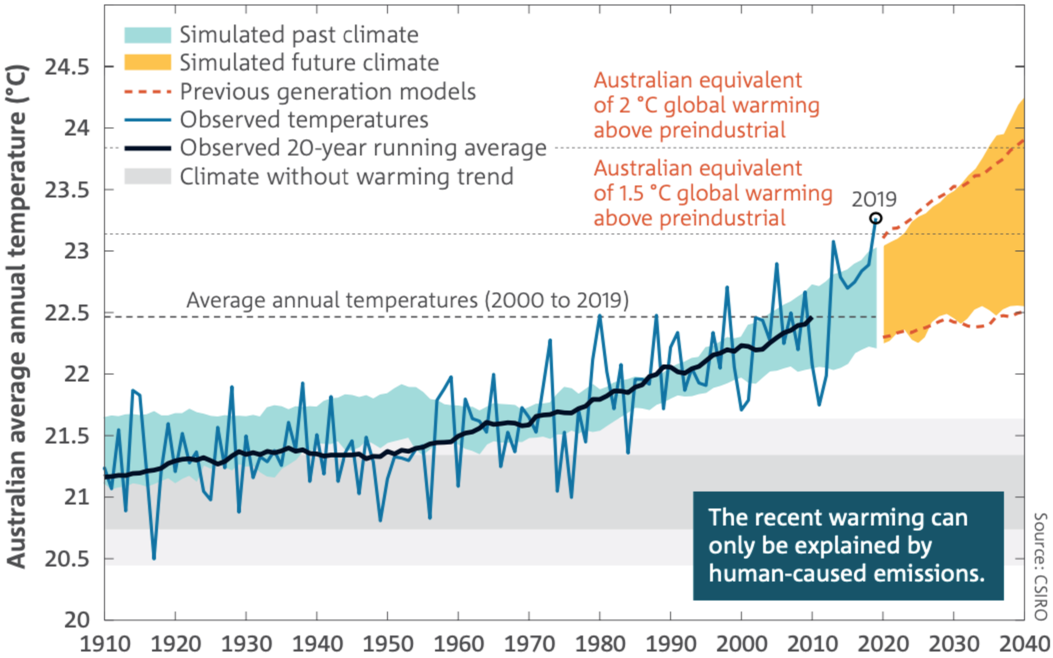

Fig. 20: Average Australian temperatures over time and projected into the future. Natural variation (without climate change) would give temperatures with the grey horizontal bands. Recent warming is due to human GHG emissions. Additional warming will cause greater average temperature changes in Australia than the global average, leaving Australia particularly exposed to more detrimental effects.

158) The **intensity, frequency and duration of heatwave extremes are projected to increase in the future due to climate change.**[173] For example, **for every °C of global temperature rise, Australians will see about 16 more heatwaves days**, with the longest heatwave increasing in length by about 5 days.

159) Already **peak heatwaves that occurred only once per 30 years in pre-industrial (1861-1890) times in Australia**, can now be expected every 5 years. **At a global warming of 1.5°C** (which we are likely to experience by the mid-2030s), **this frequency will nearly double to once every 2.7 years.** In a world **with 3°C of average warming**, Australians will see such peak heatwaves **nearly every year**.[174]

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[173] Perkins-Kirkpatrick, S. E. & Gibson, P. B. (2017) Changes in regional heatwave characteristics as a function of increasing global temperature. Sci. Rep. 7, 12256.
[174] Perkins-Kirkpatrick, S.E. and Gibson, P.B. (2017) Changes in regional heatwave characteristics as a function of increasing global temperature. Nature Scientific Reports, 7: *12256.* DOI:10.1038/s41598-017-12520-2

160) **Warming of 2.0°C would be substantively different to that of 1.5°C** above pre-industrial temperatures. In addition to the increased risks faced globally, the IPCC[175] has listed **Australia as a region where the change in risk in moving from 1.5°C of global warming to 2°C is particularly high with regard to**:

a) Water stress and drought,

b) Shifts in biomes in major ecosystems, including rainforests,

c) Changes in ecosystems related to the production of food,

d) Deteriorating air quality,

e) Declines in coastal tourism,

f) Loss of coral reefs, sea grass and mangroves,

g) Disruption of marine food webs, loss of fin fish, ecology of marine species,

h) Heat related mortality and morbidity, and

i) Ozone-related mortality.

161) **Average global temperatures in the latter half of this century, and the heat waves they induce, depend critically on human actions over the next twenty years**. Because Australia's average warming is about 1.4 times the global mean, average warming in Australia before the end of this century may reach 2.7°C (even for a rapid action SSP1-RCP2.6 sustainable pathway) to as high as 7°C (for a continued fossil fuel focused SSP5-RCP8.5 pathway) above pre-industrial levels.[176]

162) Based on the Keetch-Byram Drought Index (KBDI), an indicator of soil moisture deficit, one study[177] finds that the climate conditions expected late this century (2070 – 2100) may result in high fire potential extending to seven months in Australia (August to February). **Extreme fire danger weather like that during the Black Summer bushfire season is**

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[175] IPCC SR1.5 (2018) Intergovernmental Panel on Climate Change Special Report on Global Warming of 1.5°C. Accessed at: http://ipcc.ch/report/sr15/

[176] Grose, M. R. et al. (2020) Insights from CMIP6 for Australia's Future Climate. Earth's Fut. 8, e2019EF001469.

[177] Liu, Y., J. Stanturf, and S. Goodrick (2010) Trends in global wildfire potential in a changing climate. *For. Ecol. Manage.*, **259**, 685–697, doi:10.1016/j. foreco.2009.09.002

projected to be four times more likely if global warming reaches 2°C, compared to conditions typical in 1900.[178]

163) **Regional temperatures are key to fire development.** This is important because Australian temperatures are higher than global averages. Modelling indicates that *regional* warming of around 4°C or more above pre-industrial is sufficient to allow megafires to occur in southeast Australia irrespective of whether drought occurs simultaneously.[179] In other words, **if GHG emissions are not curbed sharply, Black Summer-like megafires may be a common Australia feature by late century even in years with plentiful rainfall**.

164) Specifically designed to study regions in Australia, the NSW/ACT Regional Climate Modelling (NARCliM)[180] project uses downscaled climate data over 50-km regions over all of Australia to measure climate changes from the `recent past' (1990–2009), to what might be expected in the `near' (2020–2039) and `far future' (2060–2079).

165) The NARCliM future projections **use a high-emissions scenario** (SRES A2).[181] **Current emissions are tracking along this scenario; whether they do in future will depend most critically on the extent to which fossil fuels contribute to the world's future energy mix.** When reading these projections, it is instructive to note that an Australian born today will spend childhood and teen years in the `near future', and middle age in the `far future'.

166) The NARCLiM study[182] found the following results for Australia **under their high-emissions scenario**:

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[178] Oldenborgh, G.J. et al. (2020) Attribution of the Australian bushfire risk to anthropogenic climate change*,* Natural Hazards and Earth System Sciences Discussions, Accessed at: https://doi.org/10.5194/nhess-2020-69

[179] Sanderson, B. M. & Fisher, R. A. (2020) A fiery wake-up call for climate science. Nat. Clim. Change. 10, 175–177

[180] Herold, N. (2018) Australian climate extremes in the 21st century according to a regional climate model ensemble: Implications for health and agriculture, Weather and Climate Extremes, 20, 54–68, https://doi.org/10.1016/j.wace.2018.01.001

[181] According to NARCLiM, "The projected warming for SRES A2 for the 2090 to 2099 period, relative to 1980 to 1999, is given by IPCC AR4 as 2.0°C to 5.9°C, with a best estimate of 3.4°C."

[182] Herold, N. (2018) Australian climate extremes in the 21st century according to a regional climate model ensemble: Implications for health and agriculture, Weather and Climate Extremes, 20, 54–68, https://doi.org/10.1016/j.wace.2018.01.001

a) **Daytime temperature extremes are projected to increase by up to 3.5°C** in the far future, depending on season and location.

b) Heatwave frequency, number and duration will increase significantly in the near and far future. **All capital cities will experience, at minimum, a tripling of heatwave days each year by the far future compared to the recent past, with the effect more extreme in the north**.

c) **Implications for mortality are severe**, with projected future climates leading to increases in mortality due to high temperatures in all examined capital cities.

d) Moderate to severe drought conditions are expected in the far future in the southwest and southeast of Australia during spring.

e) The **number of days at or above 30°C in the major Australian wheat growing regions will increase substantially**, particularly during spring when wheat is most vulnerable to temperature. Projected decreases in precipitation would **decrease the likelihood of meeting historical production levels.**

167) **The Australian Academy of Science has released a report[183] describing the risks to Australia should global warming reach 3°C or higher, as it is likely to if humanity continues its current emissions trajectory**. Some of the identified key risks to Australia at 3°C (over and above those at 1.5°C to 2°C) of global warming include:

a) **Extreme events such as heatwaves, severe storms, major floods, bushfires and coastal inundation from sea level rise would be more intense and frequent**.

b) **Many locations in Australia would become uninhabitable** due to projected water shortages.

c) Severe impacts to both flora and fauna would cause **many of Australia's ecological systems** to **become unrecognisable**,

d) Existing tree plantations would change substantially.

[183] Australian Academy of Science (2021). *The risks to Australia of a 3°C warmer world* (and references therein.) Accessed at: https:// www.science.org.au/warmerworld

e) Fisheries and aquaculture industries would experience declines in profitability, and **many aquaculture fisheries enterprises may cease to exist**.

f) **Many properties and businesses would become uninsurable**.

g) **A decline in profits and business viability would likely lead to increased unemployment and possibly higher suicide rates**.

h) **Health issues related to heat stress and acute and chronic psychological stressors would increase**.

i) **Declining river flows would reduce water availability for irrigated agriculture and increase water prices**.

j) **Crop yields would decline by 5 to 50%, depending on location**.

k) **Sea level rise would transform Australia's coastal regions, with severe impacts on natural ecosystems, urban infrastructure and rural settlements, putting the health and wellbeing of many people at increasingly severe risk.**

6.4 Possible NSW Futures

168) **Future climate change will increase many already deleterious impacts for NSW.** The severity will depend on the level of global warming (and thus emission trajectories) before net zero emissions is reached. Some risks are described below.

169) **NSW crosses five subcluster regions**[184] used to project more local future effects of climate change, namely **East Coast** (incl. Sydney), **Central Slopes** (incl. Dubbo and Narrabri), **Rangelands** (incl. Broken Hill), **Murray Basin** (incl. Wagga Wagga), and the **Southern Slopes**, (incl. Batemans Bay).[185] (See Fig. 21 below).[186]

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[184] Climate Change in Australia: Projections for Australia's NRM Regions. Accessed at: https://www.climatechangeinaustralia.gov.au/en/projections-tools/regional-climate-change-explorer/sub-clusters/

[185] Climate Change in Australia: Projections for Australia's NRM Regions. NRM Regions. Accessed at: https://www.climatechangeinaustralia.gov.au/en/overview/methodology/nrm-regions/

[186] Climate Change in Australia: Projections for Australia's NRM Regions. NRM Regions. Accessed at: https://www.climatechangeinaustralia.gov.au/en/overview/methodology/nrm-regions/

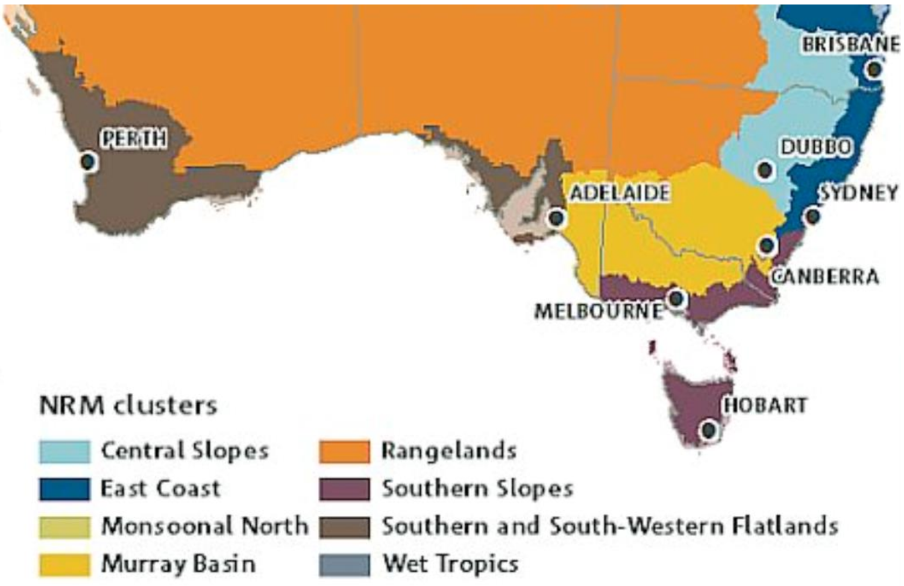

Fig 21: Colour-coded regional clusters used to project future climate.

170) Joint work[187] by the CSIRO and BoM **projects future climate conditions** by combining several global climate simulations with fine resolution "downscaled" data appropriate to local regions. **All five subclusters of NSW can expect the following in future**:

a) **Temperatures increase in all seasons, with fewer frosts in winter**.

b) **Substantial increases in the temperature on hot days, the frequency of hot days, and the duration of warm spells.**

c) **Less cool season rainfall and increased intensity of extreme rainfall events**.

In addition, **the Central Slopes NRM cluster, in which the Project would be located, can expect a climate with harsher fire weather**.

171) **For NSW, run-off, that is the water available to feed dams and rivers, will decrease markedly with the multiple effects of climate change**. It is estimated[188] that **for every one degree of global warming, runoff will be reduced by 15%,** which matches what is

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[187] Climate Change in Australia (2015): Projections for Australia's NRM Regions. Accessed at: https://www.climatechangeinaustralia.gov.au/en/climate-projections/future-climate/regional-climate-change-explorer/sub-clusters/

[188] Reisinger, A., et al. (2014) Australasia. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1371-1438.

currently being experienced. With current emissions trends leading to a possible *additional* 2°C to 3°C of temperature increase (for a total increase of 3°C to 4°C), the NSW region could be faced with water reductions of 45 – 60%, compared to mid last century.[189] This has **profound consequences for water availability for human and environmental use**.

172) The difference in global warming between 1.5°C and 2.0°C greatly increases the frequency of extreme temperatures over many regions. For southern Australia, a median of 4–8 extra heatwave days per year is projected for every additional degree of warming.[190] Consequently, **in a world with 1.5°C of warming, NSW can expect about 2–4 more heatwave days than currently, and 4-8 more with 2°C of global warming.** Should global warming reach **3°C or more**, as indicated by current policy settings in Australia and elsewhere in the world, **NSW will incur one or two more weeks in heatwave every year in addition to what it now endures.**[191]

173) The non-linear complexity of Earth's climate system is such that the most extreme of extreme temperature events do not scale simply with an additional amount of warming. One study from 2017 (before Black Summer) **concluded that major Australian cities, such Sydney or Melbourne, could therefore incur maximum summer temperatures of 50°C under 2°C of global mean warming.**[192] Penrith recorded 48.9°C (whilst many other sites in metropolitan Sydney exceeded 47°C) on 4 January 2020, at a time when global warming stands at only 1.1°C. This raises the possibility that **current models may be underestimating the extreme heat that NSW will feel at 1.5°C, let alone, at 2°C of global warming.**

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[189] ACT Climate Change Council (2020), Learning from Canberra's Climate-Fuelled Summer of Crisis, accessed at: https://www.environment.act.gov.au/__data/assets/pdf_file/0003/1611471/learning-from-canberras-climate-fuelled-summer-of-crisis.pdf

[190] Perkins-Kirkpatrick, S.E. and Gibson, P.B. (2017) Changes in regional heatwave characteristics as a function of increasing global temperature. Nature Scientific Reports, 7: *12256.* DOI:10.1038/s41598-017-12520-2

[191] Perkins-Kirkpatrick, S.E. and Gibson, P.B. (2017) Changes in regional heatwave characteristics as a function of increasing global temperature. Nature Scientific Reports, 7: *12256.* DOI:10.1038/s41598-017-12520-2

[192] Lewis, S. C., King, A. D., & Mitchell, D. M. (2017). Australia's unprecedented future temperature extremes under Paris limits to warming. Geophysical Research Letters, 44, 9947–9956. https://doi.org/10.1002/2017GL074612

7 Why We are Tracking Toward more Dangerous Climate Change

174) The world is emitting greenhouse gases on a trend that would lead to substantially more dangerous climate change. Indications that this is the case, and explicit requirements for reversing this trend significantly and quickly enough to minimise the damage are discussed in this section of this Report.

175) Specifically, I outline:

a) how current nationally determined contributions to the Paris Agreement are insufficient to hold warming to levels agreed by Paris Agreement signatories;

b) the shrinking remaining global `carbon budget' to hold warming to various levels; and

c) the gap between current and planned production of fossil fuels and limiting global warming to 1.5° or even 2°C above pre-industrial temperatures.

7.1 National Contributions to the Paris Agreement

176) **The Paris Agreement**[193] **commits signatories to "holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C."** Signatory nations, such as Australia, have made separate, voluntary, Nationally Determined Contributions (NDCs) as a first step to meet these goals.

177) In late 2019, it was estimated that the 2019 NDCs, if achieved, would result in global warming by 2100 of 2.9°C—3.4°C relative to pre-industrial levels, increasing thereafter.[194]

178) **After many countries updated their NDCs in 2020**, the UNFCCC noted in its early 2021 analysis[195] prior to the UN Conference of the Parties in Glasgow that even after consideration of the 48 new or updated NDCs submitted by 31 December 2020, the total

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[193] UN (2015), Paris Agreement, Accessed from https://unfccc.int/sites/default/files/english_paris_agreement.pdf

[194] WMO 2019, United in Science, Report prepared for the UN Climate Action Summit 2019, https://wedocs.unep.org/bitstream/handle/20.500.11822/30023/climsci.pdf

[195] UNFCCC (2021) Synthesis Report: Nationally determined contributions under the Paris Agreement, Accessed at: https://unfccc.int/process-and-meetings/the-paris-agreement/nationally-determined-contributions-ndcs/nationally-determined-contributions-ndcs/ndc-synthesis-report

GHG emissions of the Parties to the Paris Agreement was expected to be only 2.1% lower in 2030 than in 2017, falling "far short" of pathways consistent with holding global warming to 1.5°C.

179) A recent UN report[196] estimates the `emissions gap' between levels of warming relevant to the Paris Agreement and current NDCs. Specifically, this gap for 2030 is the difference between the estimated total global GHG emissions resulting from the full implementation of the NDCs and the total global GHG emissions from least-cost scenarios that keep global warming to 2°C, 1.8°C or 1.5°C with varying levels of likelihood. Compared to previous unconditional NDCs, the **new pledges for 2030 reduce projected 2030 emissions by only 7.5%, whereas a 30% reduction (on 2010 levels) is needed for 2°C and a 55% reduction is needed for 1.5°C**. The stark difference is illustrated in Fig. 22, which visually illustrates the declines that must occur by 2030 to achieve Paris Agreement goals.

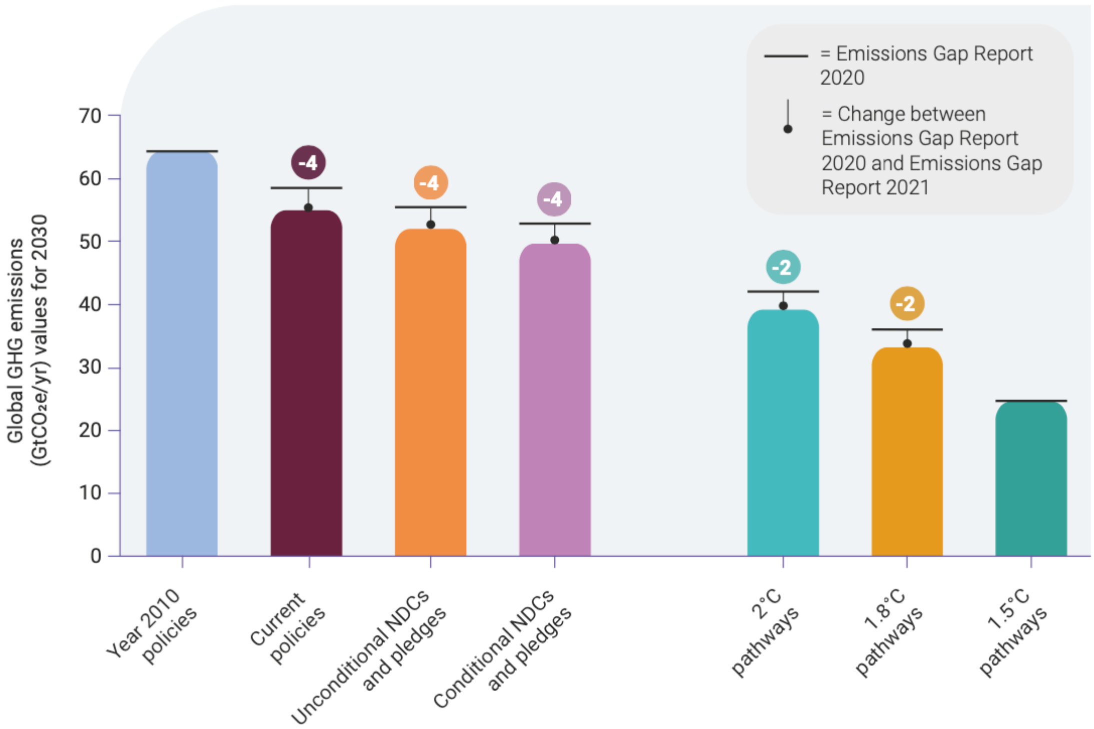

Fig. 22: Overview of changes in GHG emission projects for 2030 for different scenarios compared to global policies in 2010. Figure from the UNEP 2021 Emissions Gap Report.

[196] United Nations Environment Programme (2021) Emissions Gap Report 2021: The Heat is On – A World of Climate Promises Not Yet Delivered. Nairobi. Accessed at: https://www.unep.org/resources/emissions-gap-report-2021

180) In its most recent analysis, Climate Action Tracker[197] estimates that **global warming between 1.9°C and 3.0°C could result from current post-Glasgow commitments — if honoured** — still falling far short of the Paris Agreement targets, but slightly improved from expectations two years ago (see Fig. 23).

181) Aggravating this state of affairs, **most nations are not on track to meet their current commitments**, which if not corrected immediately, would result in even more warming. In fact, **based on current *policies* as opposed to *pledges***, Climate Action Tracker estimates that **warming could go as high as 3.6°C** (see Fig. 23).[198]

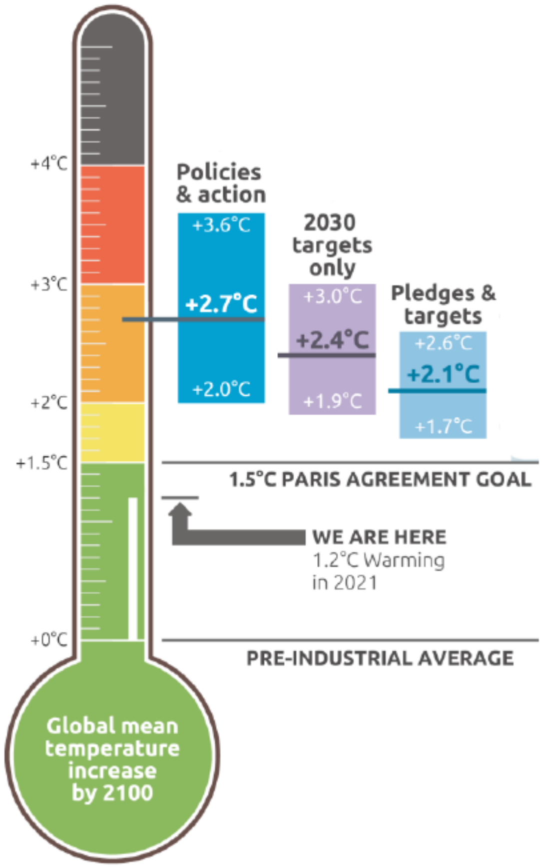

Fig. 23: Global warming projections based on pledges and policies of global nations. (Climate Action Tracker, November 2021 analysis).

182) The devastating consequences of such a world well over 2°C are discussed in subsection 6.2 of this Report.

7.2 The Global `Carbon Budget'

183) In order **to stabilise the climate at a certain average global temperature, human greenhouse gas emissions must at some point drop to net zero**. The maximum temperature reached is determined by cumulative net global anthropogenic CO_2

[197] Climate Action Tracker (2021), https://climateactiontracker.org/ Accessed 13 January 2022.
[198] Climate Action Tracker (2021), https://climateactiontracker.org/ Accessed 13 January 2022.

emissions up until the time of net zero CO_2, the level of non-CO_2 radiative forcing[199] in the decades just prior, and the effects of feedbacks in the Earth system (see subsection 4.7).[200]

184) **The 'carbon budget approach' is a conceptually simple and scientifically sound method to estimate the speed and magnitude by which emission reductions must occur in order to meet a desired warming target,**[201] **focussing on CO_2** as the primary greenhouse gas. This approach is used by the IPCC,[202,203] and was adopted by the Australian Climate Change Authority to form its 2014 recommendations[204] for Australia.

185) The manner in which CO_2 moves through the land, ocean and atmosphere is complex, but the full effect of these processes yields an ***approximately* linear relationship** (see Fig. 24)[205] **between**:

a) The **'carbon budget'**: that is, **the cumulative amount of carbon**[206] **emitted as carbon dioxide from human actions since the beginning of industrialisation** (often taken to be about 1870), and

b) The increase in average global surface temperature since that time.

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[199] Radiative forcing is the difference between how much energy from the Sun is absorbed by the Earth, and how much energy is radiated back to space. If the net forcing is zero, the Earth will remain at a stable equilibrium temperature. Positive forcing causes the temperature to rise.

[200] IPCC SR1.5 (2018) Intergovernmental Panel on Climate Change Special Report on Global Warming of 1.5°C. Accessed at: http://ipcc.ch/report/sr15/

[201] Collins, M. et al. (2013) Long-term climate change: Projections, commitments and irreversibility, in Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, edited by Stocker et al. Cambridge University Press, pp. 1029-1136.

[202] IPCC SR1.5 (2018) Intergovernmental Panel on Climate Change Special Report on Global Warming of 1.5°C. Accessed at: http://ipcc.ch/report/sr15/

[203] IPCC (2021) Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, accessed at: https://www.ipcc.ch/report/ar6/wg1/#SPM

[204] CCA (Climate Change Authority) (2014) Reducing Australia's Greenhouse Gas Emissions: Targets and Progress Review—Final Report, https://www.climatechangeauthority.gov.au/reviews/targets-and-progress-review-3

[205] IPCC (2021) Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Fig. SPM.10 accessed at: https://www.ipcc.ch/report/ar6/wg1/#SPM

[206] NB: Carbon budget numbers presented here are measured in the weight of carbon emissions, not carbon dioxide. CO_2 weighs more than the carbon it contains. CO_2-e, carbon dioxide equivalent, counts greenhouse gases whose effects have already been tallied in the budget.

186) The **budget is not annual, but cumulative: for all time—past, present and future. Once the carbon budget has been 'spent' (emitted as GHGs), emissions must be held to net zero**[207] from that point onward to avoid exceeding the target temperature. Carbon emissions budgets are generally calculated in either billions of tonnes of carbon (Gt C) or billions of tonnes of CO_2 (Gt CO_2). 1Gt CO_2 contains 0.273 Gt C.

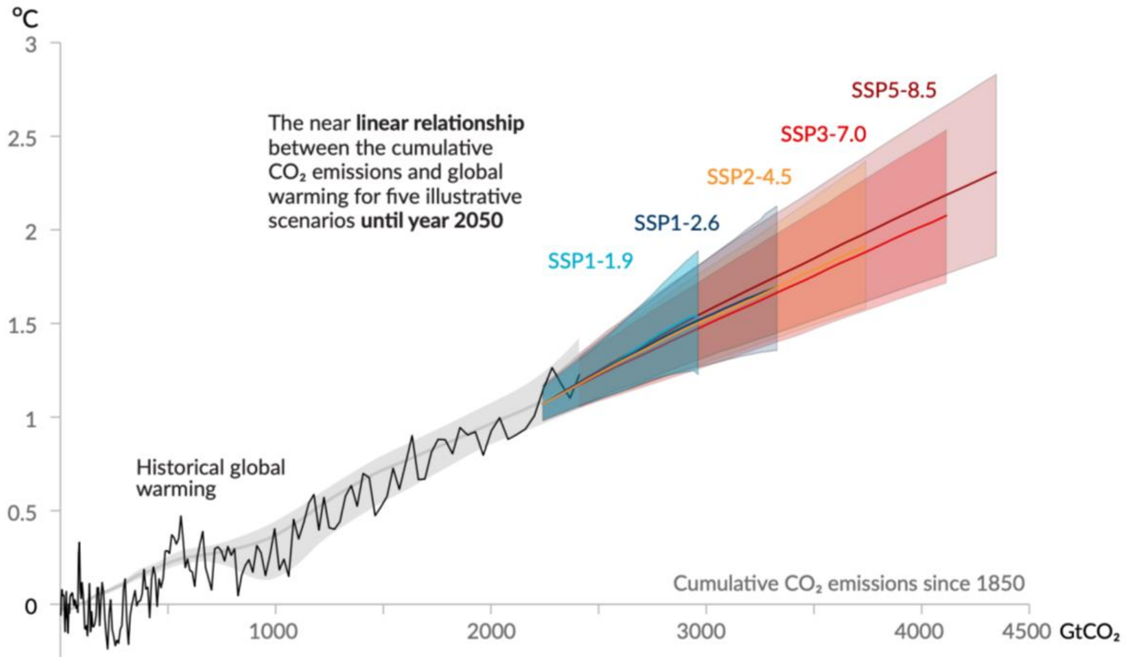

Fig. 24: Global surface temperature increase [on vertical axis in °C since the period 1850-1900] as a function of the cumulative CO_2 emissions [on horizontal axis in $GtCO_2$] projected out until the year 2050. This near linear (straight-line) relationship is the basis for computing a `carbon budget' for a particular amount of global warming. Figure is taken from the IPCC AR6 WG1 Summary for Policy Makers.

187) Several assumptions influence the size of the global carbon budget for a given warming target. Key among them are:

a) What is considered an 'acceptable' probability of meeting the target,

b) The date period used for `pre-industrial,'

c) The accounting of other greenhouse gases (particularly CH_4 and N_2O),

d) Whether or not `temporary overshoot' of the desired warming target is allowed, and

[207] NB: The term 'net zero' used here means that CO_2 emissions *into* the atmosphere are matched in magnitude by CO_2 removal *from* the atmosphere. Carbon capture and storage and many other `Negative Emission Technologies' are not yet viable at scale.

e) If, and how, carbon feedbacks in the climate system are accounted. Carbon feedback occurs when warming causes the Earth to release some of its own sequestered CO_2.

188) The goal is to ascertain the ***remaining* amount of carbon** (in the form of CO_2) **that humans can still release** into the atmosphere **without exceeding global warming at a prescribed level,** for example warming of 1.5°C. The *remaining* carbon budget, the amount humans have 'left to spend,' is **different from the total carbon budget, for three primary reasons**.

a) Substantial historical emissions from pre-industrial times through to the present have already been emitted, and must be subtracted from the total budget to arrive at the much smaller amount remaining.

b) Assumptions about the future emissions of *non*-CO_2 GHGs are implicit in carbon budget estimates. Should actual trajectories differ from those assumptions, the remaining carbon budget will change.

c) Some carbon cycle feedbacks, such as the abrupt shift of the Amazon rainforest to a savanna, GHG emissions from permafrost thaw, and the effects of increased wildfire are not accounted for in many Earth System models or in some carbon budget approaches. This could reduce the remaining carbon budget further.[208,209]

189) The most recent IPCC report (AR6, WG1)[210] gives remaining carbon budgets for selected values of global warming and for selected likelihoods of occurring. These are reproduced in Table 2 below.

190) Large uncertainties could push these remaining carbon budgets higher or lower, though neglected or underestimated positive carbon feedbacks will always work to decrease carbon budgets.

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[208] Ciais P et al. (2013) Carbon and Other Biogeochemical Cycles, in Climate Change 2013: The Physical Science Basis, Fifth Assessment Report of the IPCC, edited by Stocker TF, et al., Cambridge University Press, pp. 465–570, doi:10.1017/CBO9781107415324.015.

[209] Steffen W et al. (2018) Trajectories of the Earth System in the Anthropocene. *Proc. Natl. Acad. Sci. (USA)* doi:10.1073/pnas.1810141115 and associated Appendix https://www.pnas.org/content/pnas/115/33/8252.full.pdf

[210] IPCC (2021) Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Table SPM.2, accessed at: https://www.ipcc.ch/report/ar6/wg1/#SPM

Table 2: Remaining global carbon budgets from 2020 as given by IPCC AR6 for various temperature limits and success likelihoods

Approximate global warming relative to the period 1850-1900 until the temperature limit (°C)	Estimated remaining carbon budgets from the **beginning of 2020** (Gt CO_2) *Likelihood of limiting global warming to temperature limit*				
Temperature Limit	17%	33%	50%	67%	83%
1.5	900	650	500	400	300
1.7	1450	1050	850	700	550
2.0	2300	1700	1350	1150	900

191) Notably, higher or lower reductions in accompanying non-CO_2 GHG emissions could alter the carbon budgets by 220 Gt CO_2 or more. In this context, however, it is important to note that **AR6 carbon budgets** in Table 2 **assume that non-CO_2 emissions are reduced sharply as well. For methane, this implies at least a 30% reduction in 2030 compared with 2010, and a 50% reduction in 2050.**[211]

192) At the moment, **global methane emissions are rising, which means that remaining carbon budgets are shrinking**. In fact, since 2012, CH_4 emissions have been tracking the *warmest* scenarios assessed by the IPCC[212], and atmospheric concentrations have been rising at an increasing rate since about 2006 (refer to Fig. 2).

193) In order to establish the *remaining* carbon budgets from the beginning of 2022, the budget quantities in Table 2 must be reduced by the total CO_2 emissions released in 2020 and 2021, namely by about 80 Gt CO_2 (equivalent to 21.1 Gt C).[213]

194) **In this Report, I focus on carbon budgets that correspond to at least a 67% chance (two-in-three chance) of meeting the indicated temperature target**, noting that a 50% likelihood is equivalent to basing the most critical of environmental outcomes on the flip of a coin. Table 3 thus presents remaining carbon budgets from the beginning of 2022 for at least a 67% likelihood of limiting global warming to 1.5°C, 1.7°C and 2.0°C.

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[211] United Nations Environment Programme (2021). *Emissions Gap Report 2021: The Heat Is On – A World of Climate Promises Not Yet Delivered*. Nairobi. Accessed at: https://www.unep.org/resources/emissions-gap-report-2021

[212] Saunois, M. et al. (2020) The Global Methane Budget 2000 – 2017, Earth System Sci. Data, 12, 1561, https://doi.org/10.5194/essd-12-1561-2020

[213] Friedlingstein, P et al. (2021) Global Carbon Budget 2021, Earth Syst. Sci. Data https://essd.copernicus.org/preprints/essd-2021-386/

Table 3: Remaining global carbon budgets from 2022 for a 67% chance of holding warming to various temperature limits (rounded to the nearest 10 Gt CO_2)

Approximate global warming relative to the period 1850-1900 until the temperature limit	Paris Agreement Significance*	Estimated remaining carbon budget from the **beginning of 2022** ($GtCO_2$)
Temperature Limit		*67% likelihood of limiting global warming to temperature limit*
1.5 °C	Required Level of Effort	320
1.7 °C	Consistent	620
2.0 °C	Not Consistent	1070

195) In order to place these quantities in perspective, note that global annual emissions are now estimated to have rebounded from a small decline caused by COVID-19 restrictions, and now stand at about 40 Gt CO_2 per annum.[214] Thus, **only about 8 years remain at current emission levels before the remaining 1.5°C carbon budget** (from Table 3) **is exhausted**. This is one of many ways to understand why the period until 2030 is so critical.

7.3 The Fossil Fuel Production Gap

196) The primary reason why current global policies place the world on track for about 3°C of warming is that future fossil fuel production is not being curtailed quickly.

197) A 2021 special report by the **International Energy Agency (IEA)[215]** specifically designed for the **global energy sector** as a **roadmap** for achieving a net zero pathway (by 2050) listed (among other measures) **three significant milestones in the report's pathway that illustrate the scope of the changes required**:

a) **Beginning in 2021: No new oil and gas fields approved for development; no new coal mines or mine extensions; no new unabated coal plants approved for development.**

b) **By 2030: Phase-out of unabated coal in advanced economies.**

c) **By 2040: Phase-out of all unabated coal and oil power plants.**

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[214] Friedlingstein, P et al. (2021) Global Carbon Budget 2021, Earth Syst. Sci. Data https://essd.copernicus.org/preprints/essd-2021-386/

[215] IEA (2021) Net Zero by 2050: A Roadmap for the Global Energy Sector, accessed at: https://www.iea.org/reports/net-zero-by-2050

198) A 2015 economic analysis **based on only a 50% chance of achieving 2°C** concluded that **a third of oil reserves,**[216] **half of gas reserves, and over 80% of coal reserves** (as defined in 2015) **must remain unused** from in the period from 2010 to 2050 **in order to meet a warming target of 2°C**, above Paris Agreement goals.[217]

199) Updating this work in 2021, a new research paper[218] estimates that in order to have at least a **50% probability** of keeping the global temperature increase to about **1.5°C, 58% of oil, 59% of fossil methane gas, and 89% of coal reserves** (as identified in the 2018 reserve base) **must not be extracted**. This means that very high shares of reserves considered economic today could not be extracted if the world is to meet a global 1.5 °C target.

200) Underscoring this point are recent reports[219,220,221] that analyse the gap between different nations' expectations for the production of fossil fuels and the Paris Agreement warming target that the same nations support. The 2021 analysis shows that **governments are still planning to produce about 45% more fossil fuels by 2030 than would be consistent with a 2°C pathway and more than double than would be consistent with a 1.5°C pathway.**

201) **The disconnect between the intention to produce more fossil fuels and the commitment to reduce emissions has been called the `Production Gap'**, as shown in Fig. 25 below, taken from the latest Stockholm Environment Institute (SEI) report.[222]

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[216] Here, 'reserves' is taken to mean a subset of known resources that are defined to be recoverable under current economic conditions and have a specific probability of being produced.

[217] McGlade C and Ekins P (2015) The geographical distribution of fossil fuels unused when limiting global warming to 2°C. *Nature* 517: 187-190.

[218] Welsby, D, Price, J, Pye, S, and Elkins, P (2021) Unextractable fossil fuels in a 1.5C world, Nature, 597, Accessed at: https://www.nature.com/articles/s41586-021-03821-8

[219] SEI, IISD, ODI, Climate Analytics, CICERO, and UNEP (2019) The Production Gap: The discrepancy between countries' planned fossil fuel production and global production levels consistent with limiting warming to 1.5°C or 2°C. https://productiongap.org/2019report/

[220]SEI, IISD, ODI, E3G, and UNEP (2020) The Production Gap Report: 2020 Special Report. https://productiongap.org/2020report/

[221] SEI, IISD, ODI, E3G, and UNEP (2021) The Production Gap Report: 2021 Report. Governments' planned fossil fuel production remains dangerously out of sync with Paris Agreement limits. https://productiongap.org/2021report/

[222] SEI, IISD, ODI, E3G, and UNEP (2021) The Production Gap Report: 2021 Report. https://productiongap.org/2021report/

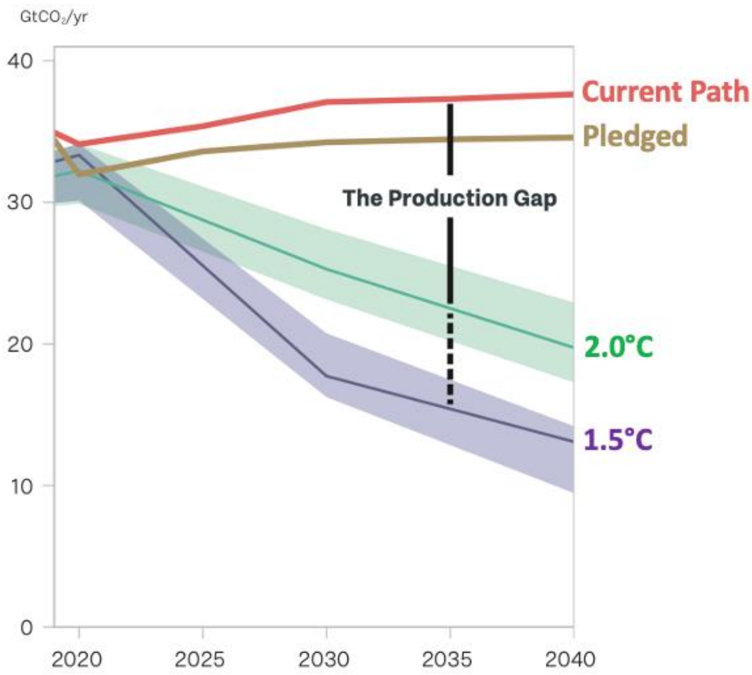

Fig. 25: Possible trajectories of global CO_2 emissions from all fossil fuels from 2019 to 2040 in units of $GtCO_2$ emitted in each year. In red is the current trajectory, whilst the gold line indicates what would be achieved if all Paris Agreement pledges were met. Lavender and turquoise trajectories reflect world fossil fuel production consistent with a 50% chance of holding warming to 1.5°C, or 66% chance of holding warming to 2.0°C, respectively. Shaded regions indicate uncertainty ranges for the 1.5°C and 2.0°C trajectories.

202) The world is currently emitting about 36 Gt CO_2 per year from fossil fuels[223] (see Fig. 4). At 2030, this must *drop* to about 18 Gt CO_2 per year or 26 Gt CO_2 per year to hold warming to 1.5°C or 2°C, respectively (central estimates). Yet current global policies associated with fossil fuel production are consistent with *increasing* the fossil CO_2 to at least 2040. In other words**, it is primarily the "overproduction" of fossil fuels that is preventing the world from being on-track to meeting a global warming limit of 1.5° – 2°C**.

203) **Furthermore, the production of each of coal, oil and gas must drop immediately and sharply to provide significant cuts across all years before 2030 for even a 50% chance of holding global warming to 1.5°C, according to the Production Gap Report. For a 66% chance of holding warming to 2°C, the report concludes that oil and gas production must fall after 2030, and coal production must steadily and quickly decline well before 2030.**[224] (See Fig. 26 below).

[223] Friedlingstein, P et al. (2020) Global Carbon Budget 2020, Earth Syst. Sci. Data, 12, 3269-3340, https://doi.org/10.5194/essd-12-3269-2020 Table 6 on p3292 noting units there are GtC not $GtCO_2$.
[224] SEI, IISD, ODI, E3G, and UNEP (2021) The Production Gap Report: 2021 Report. https://productiongap.org/2021report/

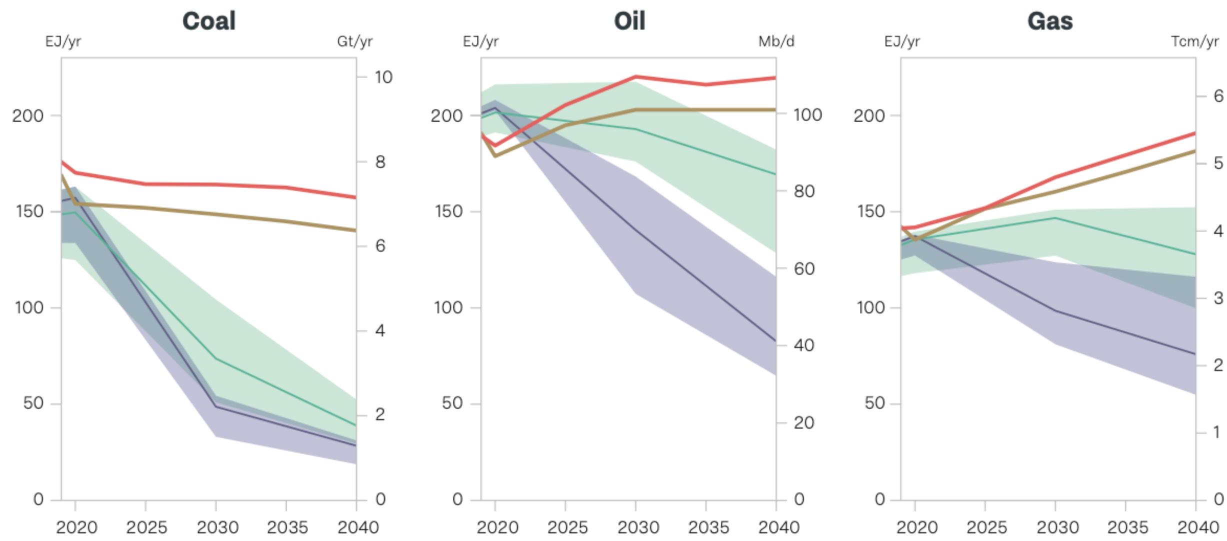

Fig. 26: Global emissions trajectories for coal, oil and gas production based on current production and projections (red) and as implied by climate pledges (gold). Also shown is a range of trajectories consistent with holding global warming to 2.0°C with a 66% chance (light green), and with holding global warming to 1.5°C with a 50% chance (lavender). From SEI et al. 2021.[225]

204) Redressing this fossil fuel production gap cannot be met by *adding* fossil fuel development, even that which may have already planned. Instead, **new fossil fuel development and expansion must cease, and ageing facilities brought to rapid close if global warming is to be halted at 1.5°C or even 2.0°C above pre-industrial times**. The longer we wait, the more difficult the transition becomes.

7.4 Australia's Contribution

205) In this subsection, I examine Australia's contribution to global warming from the three perspectives discussed earlier, namely emission trajectories and NDCs to the Paris Agreement, Australia's share of the global carbon budget, and Australia's contribution to the Production Gap.

7.4.1 Australia's NDC to the Paris Agreement and Current Emissions Trajectory

206) As a nation, **Australia's Paris Agreement NDC is to reduce its emissions by 26%–28% (on 2005 levels) by 2030.**[226] It has also stated an ambition to reach net zero emissions by

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[225] SEI, IISD, ODI, E3G, and UNEP (2021) The Production Gap Report: 2021 Report. https://productiongap.org/2021report/

[226] Commonwealth of Australia, Australia's 2030 Emissions Reduction Target Fact Sheet, https://pmc.gov.au/sites/default/files/publications/fact_sheet-aus_2030_climate_change_target.pdf

2050.[227] Australia did not update its NDC targets in 2020, whereas many other nations did so. Since Australia's emissions were 624 Mt CO_2-e in 2005,[228] a reduction of (at least) 26% implies emissions in 2030 of no more than 462 Mt CO_2-e.

207) As Fig. 27 below shows, there is no indication that such a decline is occurring based on the last five years of available Paris Agreement reporting data (which extends only to 2019). On current trends, then, **Australia's emission pathway is thus inconsistent with holding warming to 1.5°C**.

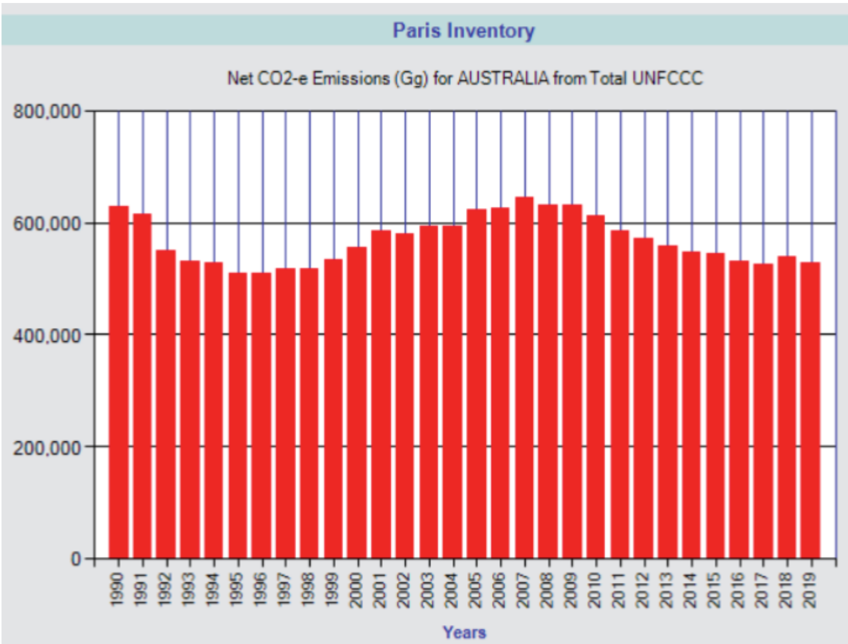

Fig 27: Australia's trend since 1990 in total emissions reported for the Paris Agreement Inventory. The plot is taken from the National Greenhouse Gas Inventory (NGGI) website. Note that the units are Gg (Giga grams) of CO_2-e, which is the same as Kt CO_2-e. (To convert to Mt CO_2-e, numbers on the vertical axis should be divided by 1000.)

208) **Australia's 2030 NDC target has been rated "highly Insufficient"** (by Climate Action Tracker)[229] **to hold global warming to below 2°C, let alone 1.5°C.** The "Highly insufficient" rating indicates that Australia's climate policies and commitments are not Paris Agreement compatible. Their analysis indicates that **Australia's 2030 emissions reduction target is consistent with warming of 4°C if all other countries followed a similar level of ambition.**

209) Another perspective on the NDC target is provided by the Australia-focussed component of a six-part series of reports[230] (CAT Report) examining how countries can

[227] See, e.g. https://www.pm.gov.au/media/australias-plan-reach-our-net-zero-target-2050
[228] National Greenhouse Gas Inventory, https://ageis.climatechange.gov.au
[229] Climate Action Tracker (2021), https://climateactiontracker.org/countries/australia/
[230] Climate Action Tracker (CAT) (2020) Scaling up Climate Action Australia, Accessed at: https://climateactiontracker.org/publications/scalingup/

scale up climate action in four key sectors: electricity supply, transport, industry, and buildings.

210) **The CAT Report[231] lists reduction targets for each of these sectors for years 2030, 2040 and 2050 that begin with Australia's current emission profile and reduce it over time in a manner consistent with holding warming to 1.5°C.** The result is shown in Fig. 28 as a combined pathway for Australia's emissions.

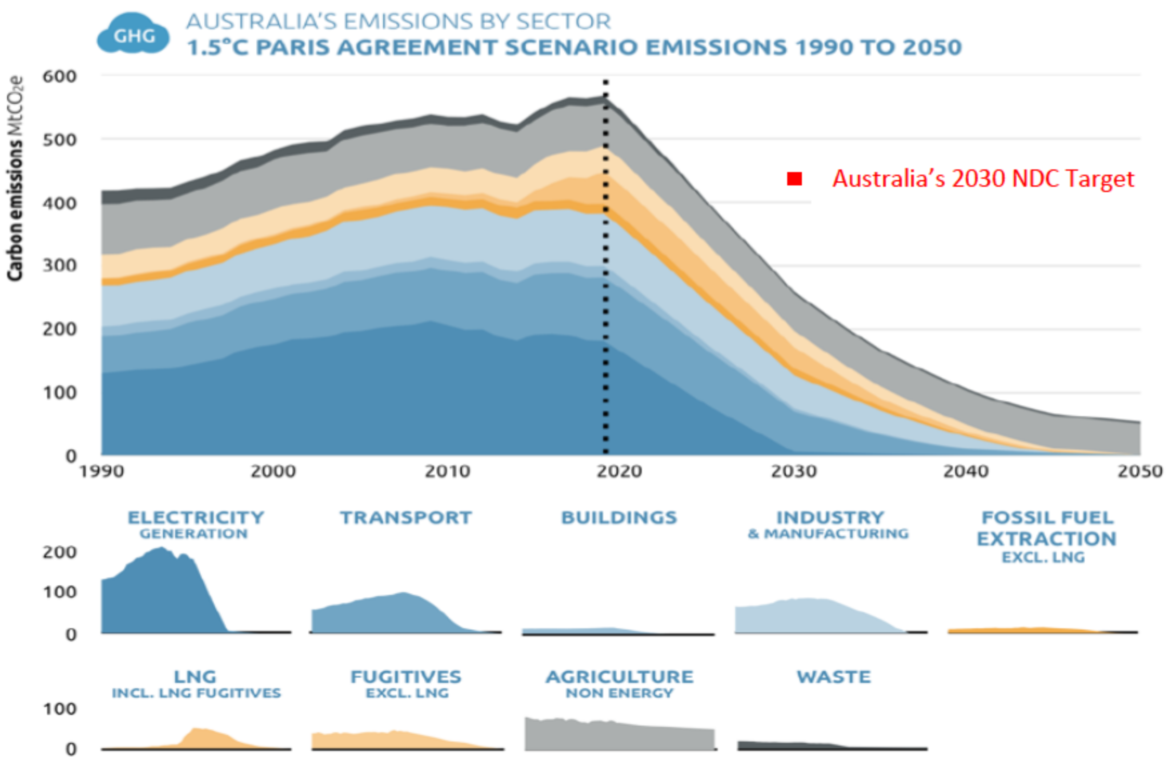

Fig. 28: A combined pathway for Australian sectoral emissions that is consistent with holding global warming to 1.5°C (according to CAT 2020). Negative emissions from land sector sinks are not shown, but could enable net zero in emissions 2050. The red square indicates Australia's 2030 Paris Agreement target over all sectors of the Australian economy. Figure from CAT 2020 report.

211) Australia's stated policy goal[232] to reduce its emissions by 26%–28% (on 2005 levels) by 2030 translates to a 2030 target of 449–462 Mt CO_2-e.[233] Examination of Fig. 28 above

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[231] Climate Action Tracker (CAT) (2020) Scaling up Climate Action Australia, Accessed at: https://climateactiontracker.org/publications/scalingup/

[232] Commonwealth of Australia, Australia's 2030 Emissions Reduction Target Fact Sheet, https://www.pmc.gov.au/sites/default/files/publications/fact_sheet-aus_2030_climate_change_target.pdf

[233] Note: CO_2-e is a commonly used measure that combines the effects of different greenhouse gases into an "equivalent" amount of CO_2. Unless otherwise stated, it refers to the effects of GHGs over a 100-year time frame after they are emitted.

shows that **Australia's current 2030 target lies far above the combined sectoral pathway consistent with 1.5°C.**

7.4.2 Australia's share of the Remaining Global Carbon Budget

212) **The remaining carbon budgets** presented in Table 3 **for the whole globe can be translated into notional remaining carbon budgets for regional areas, such as Australia or NSW** by considering an `appropriate' fractional amount. Arguments can be made as to how much a region can or should be allowed to emit, based on history, industrial base, international trade, population and ethical or normative considerations. Nature is blind to these distinctions.

213) **Regional carbon budgets can be formulated in any of a number of ways, each with its own set of driving principles**. Examples[234,235,236,237] include:

a) Remaining carbon budgets are divided equally on a per capita basis;

b) Remaining carbon budgets are divided in proportion to current emissions;

c) Responsibility for emissions reductions is based on past emissions;

d) Remaining burden to reduce emissions is based on fraction of world GDP;

e) Per capita emissions are set equal across the globe at some fixed point in future;

f) Some combination of the above.

214) **For this report, the remaining carbon budgets** of Table 3 **are apportioned equally among the world's population as they are expected to be in 2040** (sometimes referred to as the `Equality' or `Contraction and Convergence' approach), to arrive at notional

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[234] Carbon Brief (2014) How to divide up carbon budgets fairly, Accessed at: https://www.carbonbrief.org/how-to-divide-up-carbon-budgets-fairly

[235] Climate Change Council (2018) What is a Carbon Budget? Accessed at: https://www.environment.act.gov.au/__data/assets/pdf_file/0006/1297707/What-is-a-Carbon-Budget.pdf

[236] Rodriguez-Fernandez, L, et al. (2020) Allocation of Greenhouse Gas Emissions Using the Fairness Principle: A Multi-Country Analysis, and references cited therein. Sustainability, 12, 5839. Accessed at: https://www.mdpi.com/2071-1050/12/14/5839

[237] CCA (Climate Change Authority) (2014) Reducing Australia's Greenhouse Gas Emissions: Targets and Progress Review—Final Report, https://www.climatechangeauthority.gov.au/reviews/targets-and-progress-review-3

population share values for Australia and NSW. This approach has been chosen because it is relatively simple to calculate, and because it has been shown to lie in the middle of a spectrum of choices for Australia's fair share of the global emissions reduction burden. An analysis aimed at developing a GHG budget for Victoria[238] has shown that an `Equal per capita 2040 convergence' approach produced a value that was the middle of five approaches considered.

215) For this estimate, the relevant projected 2040 populations[239,240,241] are taken to be: 9.20 billion (world), 33.6 million (Australia), and 10.6 million (NSW). Results are given in Table 4 below. Note that the carbon budget numbers for Australia and NSW are in *millions* of tonnes of carbon dioxide (Mt CO_2), not *billions* of tonnes of carbon dioxide (Gt CO_2).

Table 4: Remaining carbon budgets to limit (with a 67% chance) global warming to various levels, apportioned by projected 2040 population, and rounded to the nearest 10 Gt or Mt CO_2

Share based on equal 2040 per capita share (`Equality share')	1.5°C (67% chance)	1.7°C (67% chance)	2.0°C (Not Paris compliant) (67% chance)
World	320 **Gt CO_2**	620 **Gt CO_2**	1070 **Gt CO_2**
Australia	1170 **Mt CO_2**	2260 **Mt CO_2**	3910 **Mt CO_2**
New South Wales	370 **Mt CO_2**	710 **Mt CO_2**	1230 **Mt CO_2**

216) To put these local carbon budgets in perspective using the most recent National Greenhouse Gas Inventory[242] data, note that Australia directly emitted about 374 million tonnes of CO_2 in 2019, while NSW emitted 98 million tonnes of CO_2 in that year. (For the

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[238] Meinshausen, M., Robiou Du Pont, Y. and Talberg, A. (2018), Greenhouse Gas Emissions Budgets for Victoria, Briefing Paper for the Independent Expert Panel on Interim Targets, May 2018. Accessed at: https://www.climatechange.vic.gov.au/__data/assets/pdf_file/0016/421702/Greenhouse-Gas-Emissions-Budgets-for-Victoria.pdf . See in particular, their Table 3.

[239] United Nations (2019) Population data, Standard Projections. Accessed at: https://population.un.org/wpp/Download/Standard/Population/, using medium fertility variant

[240] Australia Bureau of Statistics (2018) https://www.abs.gov.au/statistics/people/population/population-projections-australia/latest-release#data-download , using their middle series

[241] New South Wales Government (2019) Accessed at: https://www.planning.nsw.gov.au/Research-and-Demography/Population-projections/Projections**Error! Hyperlink reference not valid.**

[242] National Greenhouse Gas Inventory, maintained by the Australian Government's Department of the Industry, Science, Energy and Resources. Accessed at http://ageis.climatechange.gov.au/

purposes of carbon budget comparisons, only CO_2 emissions are counted, not other GHGs.) **Thus, on current trends, only three years remain of Australia's 'equality' carbon budget for a 67% chance of achieving 1.5°C; about four years remain for NSW's portion.**

217) If the **Australian Government's current 2030 total GHG target** of 26 – 28% reductions *on 2005 levels*, **were applied to Australia's CO_2 only emissions**, then the 453 Mt CO_2 emitted in 2005 would drop to between 326 and 335 Mt CO_2 in 2030. If the highest ambition of 326 Mt CO_2 were approached with a linear drop from 2019 to 2030, **then by 2030 Australia will have** emitted about 3,850 Mt CO_2 over that period and thus **nearly exhausted its equality share of even the 2.0°C carbon budget** shown in Table 4. I note that 2.0°C of warming is not compatible with the Paris Agreement, and its climate consequences are severe (as discussed in Section 6.)

218) The IPCC AR6 carbon budgets used here as a starting point are predicated on the assumption that deep reductions in methane occur concurrently – at least a 30% reduction in 2030 compared with 2010, and a 50% reduction by 2050 (see paragraph 191). In 2010, Australia's methane emissions were 4.86 Mt CH_4. Since then, they have dropped only slightly to 4.48 Mt CH_4 in 2019,[243] a drop of only 7.8% over that period. **If Australia fails to reduce its methane emissions much more quickly, its share of the remaining carbon budget will shrink even faster**.

219) A recent independent report[244] has reassessed Australia's emissions targets, using the carbon budget methodology used by the Government-established Australian Climate Change Authority (CCA) to arrive at its 2014[245] and 2015[246] recommendations for Australian GHG reduction targets, namely, a 40 – 60% reduction on 2000 levels by 2030.

[243] National Greenhouse Gas Inventory, maintained by the Australian Government's Department of the Industry, Science, Energy and Resources. Accessed at http://ageis.climatechange.gov.au/

[244] Hewson, J., Steffen, W., Hughes, L, and Meinshausen, M. (2021) Australia's Paris Agreement Pathways: Updating the Climate Change Authority's 2014 Emissions Reduction Targets, https://www.climatecollege.unimelb.edu.au/files/site1/docs/%5Bmi7%3Ami7uid%5D/ClimateTargetsPanelReport.pdf

[245] CCA (Climate Change Authority) (2014) Reducing Australia's Greenhouse Gas Emissions: Targets and Progress Review—Final Report, https://www.climatechangeauthority.gov.au/reviews/targets-and-progress-review-3

[246] CCA (Climate Change Authority) (2015) Final Report on Australia's Future Emissions Reduction Targets, https://www.climatechangeauthority.gov.au/sites/default/files/2020-07/Final-report-Australias-future-emissions-reduction-targets.pdf

The new report concludes that in order to be consistent with holding warming to 1.5°C with just a 50% chance, Australia's 2030 emissions reduction target must be 74% below 2005 levels, with net-zero emissions reached by 2035. This required level of emissions reduction by 2030 is nearly three times that of Australia's Paris NDC.

7.4.3 Australia and the Production Gap

220) Australia's (and NSW's) effect on global warming and climate change goes far beyond its direct emissions (or Scope 1) of greenhouse gases. **Australia has a large indirect contribution to climate change through the emissions of countries that burn our nation's exported fossil fuels. These are called 'Scope 3' emissions.**

221) Although the *National Greenhouse and Energy Reporting Act 2007* (the NGER Act)[247] does not require reporting of Scope 3 emissions for Australian entities, all emissions arising directly or indirectly from an activity lead to global warming and climate change, regardless of where they are emitted. Thus, **all emissions, including Scope 3 emissions** released when fossil fuels are combusted by any end user, **must be included when considering the effect on the climate of a given activity. To do otherwise is to assume that the fuel is never used for its intended purpose.**

222) **Australia is the world's** second **leading exporter of coal** (by weight)[248] **and the largest exporter of LNG.**[249] Under government projections analysed in recent international reports,[250,251] **Australia's extraction-based emissions**[252] **from fossil fuel (coal and gas) production are expected to nearly double by 2030 compared to 2005 levels**, indicating

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[247] Accessed at: https://www.legislation.gov.au/Details/C2019C00044
[248] International Energy Agency (2021) Coal 2021 https://www.iea.org/reports/coal-2021
[249] International Gas Union (IGU 2021), 2021 World LNG Report. https://www.igu.org/resources/world-lng-report-2021/
[250] SEI, IISD, ODI, Climate Analytics, CICERO, and UNEP. (2019). The Production Gap: The discrepancy between countries' planned fossil fuel production and global production levels consistent with limiting warming to 1.5°C or 2°C. http://productiongap.org/
[251]SEI, IISD, ODI, E3G, and UNEP. (2020). The Production Gap Report: 2020 Special Report. https://productiongap.org/2020report/
[252] `Extraction-based' emissions are part of a system of accounting that attributes greenhouse gas emissions from the burning of fossil fuels to the location of fuel extraction. It is an alternate, scientifically valid way to account for emissions.

that **Australia is a major contributor to the Production Gap**[253] **between global intended fossil fuel production and the Paris agreed warming target range**.

223) **Australian Government modelling published in 2021 anticipates (Scope 1 and 2) emissions from coal mining to remain constant over the period 2019 to 2030, implying that the total amount of coal extracted annually will stay approximately the same over this period.** Oil and gas extraction emissions, on the other hand, are projected to rise by 7% over the period. [254] **These forecasts are highly inconsistent with trends in coal, gas and oil production required to hold warming to 1.5°C, and for coal, highly inconsistent with even holding warming to 2.0°C** (see Fig. 26).

224) **Recent analysis indicates that 95% of Australia's coal reserves**[255] **– and globally 89% of all coal reserves – must stay in the ground in order for the world to have a 50% chance of holding warming to 1.5°C** (global carbon budget of 580 Gt CO2).[256]

225) Yet, Australia has more capacity in export-oriented coal projects in the pipeline than any other country by far, as illustrated in Fig. 29, taken from a 2021 report of the IEA.[257] Australia also leads in the capacity of mine re-openings per country. [258] **Without changes to current plans, Australian coal exports will contribute to the global warming Production Gap, disproportionately so, for decades to come.**

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[253] SEI, IISD, ODI, Climate Analytics, CICERO, and UNEP. (2019). The Production Gap: The discrepancy between countries' planned fossil fuel production and global production levels consistent with limiting warming to 1.5°C or 2°C. http://productiongap.org/

[254] Department of Industry, Science, Energy and Resources (2021) Australia's emissions projections 2021. See their Tables 8, 9, 15 and associated text. Accessed at: https://www.industry.gov.au/data-and-publications/australias-emissions-projections-2021

[255] Here, reserves is taken to mean coal that is technically and economically proven given market conditions at the time of study, which is 2018.

[256] Welsby, D, Price, J, Pye, S, and Elkins, P (2021) Unextractable fossil fuels in a 1.5C world, Nature, 597, Accessed at: https://www.nature.com/articles/s41586-021-03821-8

[257] International Energy Agency (2021) Coal 2021 https://www.iea.org/reports/coal-2021

[258] International Energy Agency (2021) Coal 2021 https://www.iea.org/reports/coal-2021

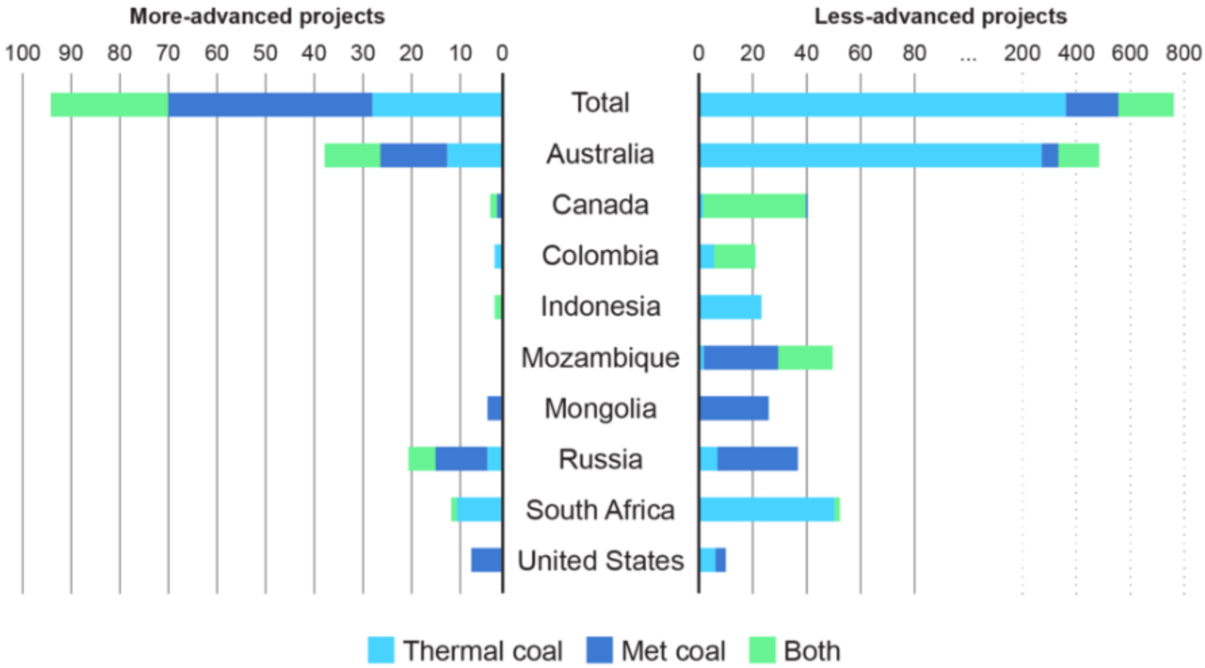

Fig. 29: Top countries by the capacity (measured in Mt of coal per annum) of new export projects for coal, as assessed by the IEA in 2021. `More-advanced' projects are those that have been approved and obtained a final investment decision or are under construction, while `less-advanced' projects are at the feasibility or environmental assessment stage, or they are awaiting approval. `Met' coal is metallurgical (or coking) coal.

7.5 NSW's Contributions

226) In this subsection, I examine NSW's contribution to global warming from the perspectives of emission trajectories, share of the global carbon budget, and contribution to the Production Gap.

7.5.1 NSW's Current Emissions Trajectory

227) **NSW has committed to achieving zero net emissions by 2050, with an interim target to reduce emissions by 50% below 2005 levels by 2030,** representing a considerable increase in ambition from its previous 2030 target of 35% reduction.[259]

228) Whereas NSW's total Scope 1 emissions did drop between 2007 and 2015, the trend has been rather flat since then, as illustrated in Fig. 30, which is taken from the national GHG Inventory.[260]

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[259] NSW Government (2021) Net Zero Plan Stage 1: 2020-30 Implementation Update. Accessed at: https://www.environment.nsw.gov.au/research-and-publications/publications-search/net-zero-plan-stage-1-2020-30-implementation-update
[260] National Greenhouse Gas Inventory. Accessed at http://ageis.climatechange.gov.au/

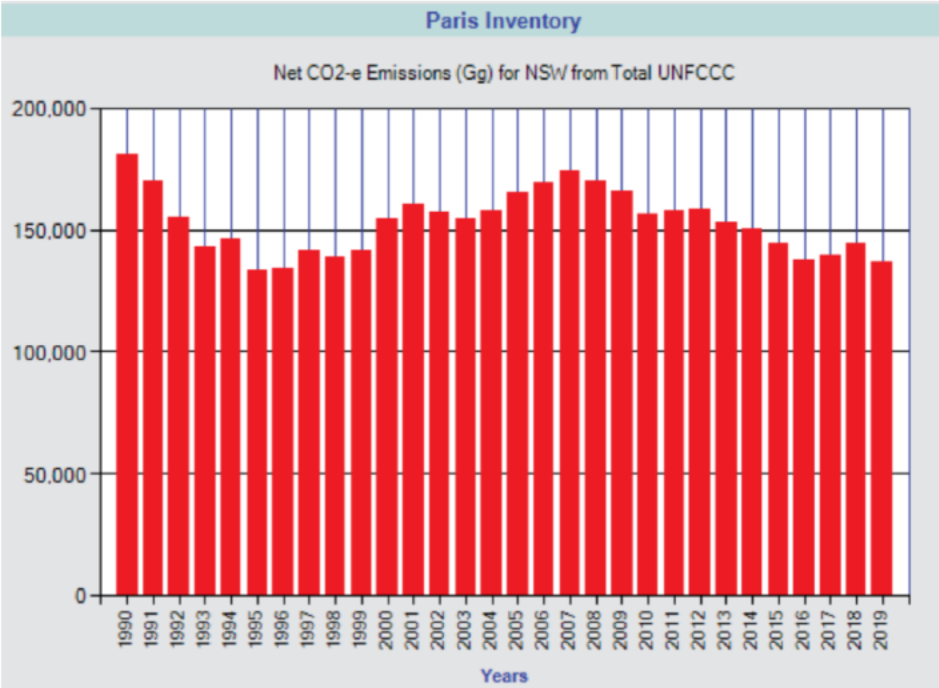


Fig. 30: New South Wales' trend since 1990 in total Scope 1 GHG emissions. The plot is taken from the National Greenhouse Gas Inventory website. Note that the units are Gg (Giga grams) of CO_2-e, which is the same as Kt CO_2-e. (To convert to Mt CO_2-e, numbers on the vertical axis should be divided by 1000.)

229) **In order to achieve a 50% reduction on total 2005 GHG emissions**, which were 165 Mt CO_2-e, **NSW's emissions in 2030** must be no more than 83 Mt CO_2-e, **requiring a considerable drop from its current emissions**, at annual rate of about 3.75% from now until 2030.

230) As I show in subsection 8.2, **the approximately 11.4 Mt CO_2-e** (Scope 1) **expected to be emitted by the Project up to 2030 will make meeting NSW's emissions target considerably more difficult to achieve.**

7.5.2 NSW's Share of the Remaining Global Carbon Budget

231) Table 4 gives NSW's share of the world's remaining carbon budgets for holding global warming to each of 1.5°C, 1.7°C and 2.0°C, with at least a 67% chance, as 370 Mt CO_2, 710 Mt CO_2, and 1,230 Mt CO_2, respectively. The most recent National Greenhouse Gas Inventory[261] data show that NSW emitted 98 million tonnes of CO_2 in 2019. (For the purposes of carbon budget comparisons, only CO_2 emissions are counted, not other

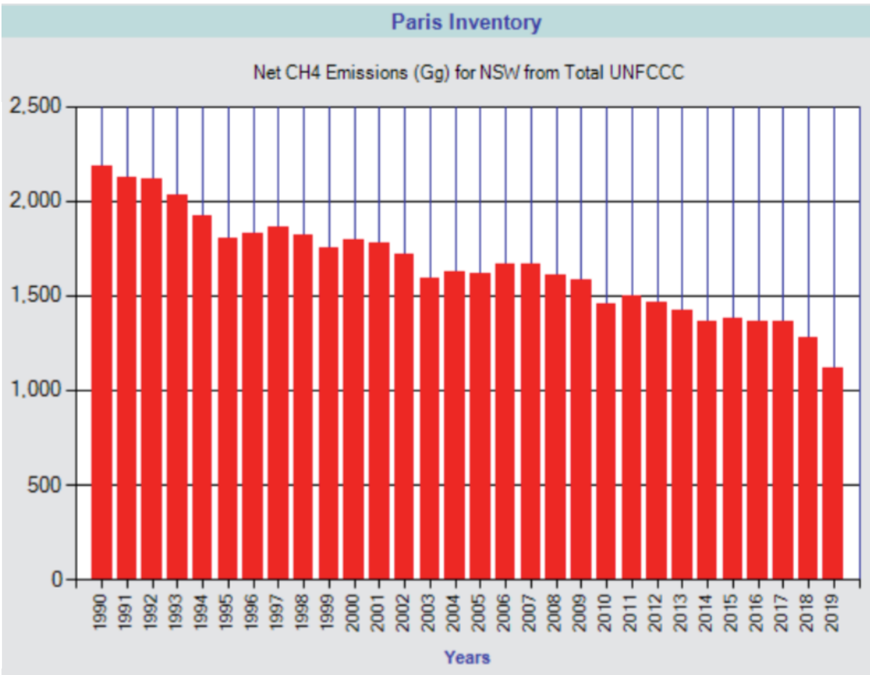
[261] National Greenhouse Gas Inventory, maintained by the Australian Government's Department of the Industry, Science, Energy and Resources. Accessed at http://ageis.climatechange.gov.au/

GHGs.) **Consequently, NSWs 'equality' carbon budget for a 67% chance of achieving 1.5°C will be exhausted by 2026 on current emission rates.**

232) If **NSW's 2030 total GHG target** of 50% reductions *on 2005 levels* **were applied to its CO_2 only emissions**, then the 112 Mt CO_2 emitted in 2005 would drop to 56 Mt CO_2 by 2030. Approaching that result linearly between 2019 to 2030, **NSW will have** emitted 848 Mt CO_2 over that period, and thus, **`overspent' twice over its share of the remaining 1.5°C carbon budget, overshot even its 1.7°C remaining carbon budget, and emitted two-thirds of its share of a 2.0°C budget.** I note that 2.0°C of warming is not compatible with the Paris Agreement.

233) On the other hand, up until this point, NSW has been on a trend of declining methane emissions, as can be seen in Fig. 31. In 2010, NSW's methane emissions were 1.45 Mt CH_4. Since then, they have dropped to 1.12 Mt CH_4 in 2019.[262] To achieve a 30% reduction in methane on 2010 levels by 2030, as is assumed in the carbon budget assumptions used by the IPCC AR6 Report (see paragraph 191)), NSW CH_4 emissions will need to drop to 1.02 Mt CH_4 by 2030. **NSW is on its way to achieving this specific 2030 goal for methane, but approving further coal projects, whose primary Scope 1 emissions are from fugitive methane, has the potential to derail the effort.**

Fig. 31: The trend in New South Wales' methane emissions since 1990 are shown. The plot is taken from the NGGI website. Note that the units are Gg (Giga grams) of CH_4, which is the same as Kt CH_4. (To convert to Mt CH_4, numbers on the vertical axis should be divided by 1000.)



[262] National Greenhouse Gas Inventory, maintained by the Australian Government's Department of the Industry, Science, Energy and Resources. Accessed at http://ageis.climatechange.gov.au/

234) All coal seams contain some level of gas; these gases escape (become `fugitive') during both open-cut and underground mining operations. In 2019, fugitive methane emissions from coal mining in NSW were nearly 80% of all methane emissions from agriculture in the state, as illustrated in Fig. 32, in which agricultural CH_4 emissions are shown in green and fugitive coal mining CH_4 emissions in black.

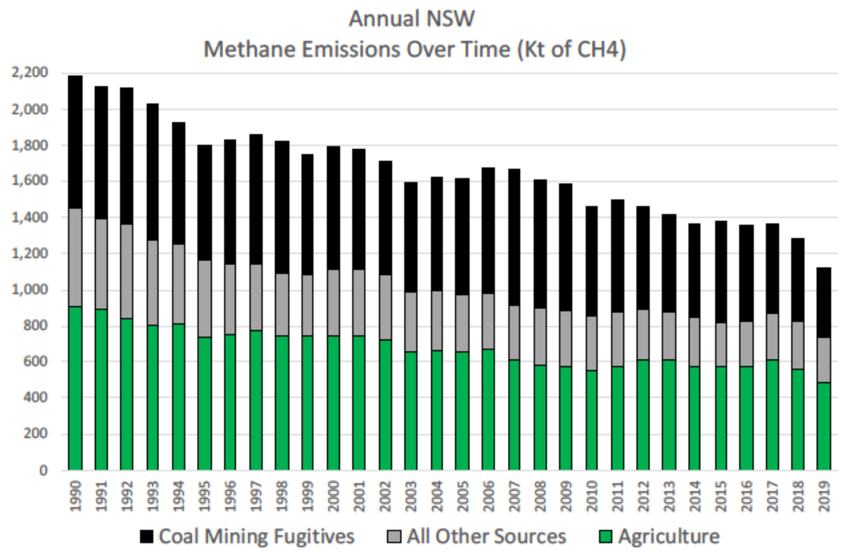


Fig. 32: Trend in annual New South Wales methane (CH_4) emissions from agriculture (green), fugitive emissions from coal mining (black), and all other sources (grey). Data are taken from the National Greenhouse Gas Inventory; units are kilotonnes of methane (Kt CH_4).

7.5.3 NSW and the Production Gap

235) **As the world's fifth largest producer of coal, and world's largest exporter of black coal,[263] Australia has an enormous responsibility, and an enormous opportunity to contribute to closing the Production Gap to a climate stabilised well below 2°C of warming compared to pre-industrial times. NSW would be central to such an effort.** Despite this, the Commonwealth Government is anticipating steady coal production through 2030,[264] coal production in NSW, one of Australia's two largest black coal-producing States, shows no sign yet of declining.

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[263] IEA data for 2019-2020 referenced by Geoscience Australia. Accessed at: https://www.ga.gov.au/digital-publication/aecr2021/coal#data-download-section

[264] Department of Industry, Science, Energy and Resources (2021) Australia's emissions projections 2021. See their Tables 8, 9, 15 and associated text. Accessed at: https://www.industry.gov.au/data-and-publications/australias-emissions-projections-2021

236) In 2019-20, production of black coal in Australia fell slightly from its all-time peak the year before, but the production in NSW continued to grow.[265] The trend in annual production of black coal NSW is shown in Fig. 33. Comparison of this historical plot with the future trend in coal production required in order to hold global warming to between 1.5°C to 2.0°C (see Fig. 26) shows the **huge magnitude of reduction required if NSW is to align its production with Paris Agreement targets.**

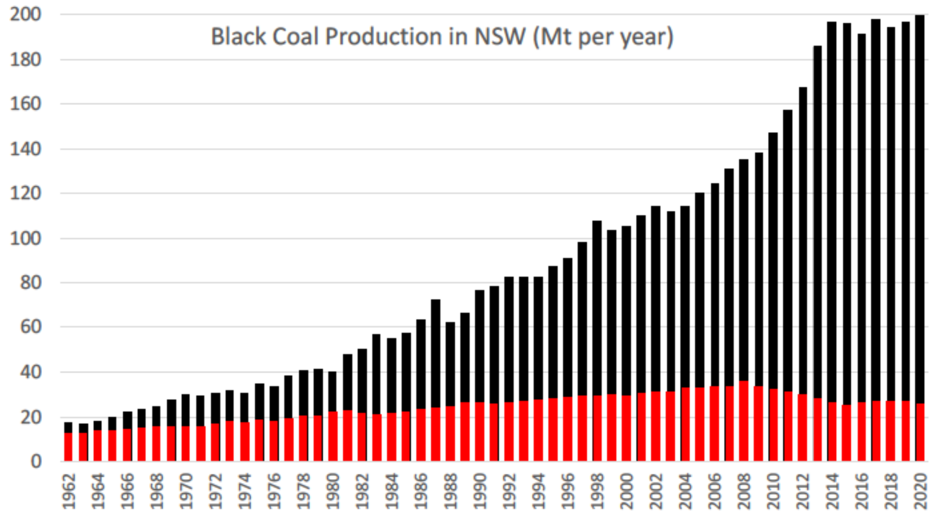

Fig. 33: NSW black coal production in thousands of tonnes (Kt) from 1960-61 to 2018-19. In red is the part of this black coal that is consumed in New South Wales in each year. Data are from Table I4 of Australian Energy Statistics 2021.

237) Cumulatively, over the past six decades, NSW has produced 5.0 billion tonnes (Gt) of black coal.[266] Using a carbon content of typical bituminous coal,[267] this is equivalent to about 12.2 Gt CO_2 due to combustion at its final destination, or about 0.88% of the world's total CO_2 emissions from fossil fuels and cement production over this time,[268] despite NSW accounting for only about 0.10% of the world's population.

238) **In the ten years 2011 to 2020, the average *annual* production of NSW black coal has been responsible, when combusted, for about 459 Mt CO_2-e released into the**

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265 Australian Government (2021) Australian Energy Statistics, including Table I4, Dept of Industry, Science, Energy and Resources, September 2021. Accessed at: https://www.energy.gov.au/publications/australian-energy-update-2021

266 Australian Government (2021) Australian Energy Statistics, including Table I4, Dept of Industry, Science, Energy and Resources, September 2021. Accessed at: https://www.energy.gov.au/publications/australian-energy-update-2021https://www.energy.gov.au/publications/australian-energy-update-2021

267 Australian Government (2021) National Greenhouse Accounts Factors. See their Table 1.

268 Using data downloaded from https://ourworldindata.org/co2-emissions

atmosphere every year. These Scope 3 emissions from black coal combustion are over three times the State's entire average Scope 1 annual CO_2-e emissions over the same period. On a per tonne basis, these Scope 3 emissions have an identical effect on NSW's future climate as do the Scope 1 emissions, yet the total amount is three times larger.

239) **As a result, NSW is a major contributor to the Production Gap**[269] between global intended fossil fuel production and the Paris Agreement agreed warming target range. In this sense, **NSW is indirectly working against global warming being held to 1.5°C (and even to 2.0°C), through the large Scope 3 emissions associated with its black coal production, primarily for export**. Any new or expanded fossil fuel development in the State will aggravate this situation.

240) The size of this effect compared to NSW's own domestic Scope 1 emissions indicates that **the State could have a major role in limiting climate change by quickly reducing its production of fossil fuels, particularly those which are exported**.

[269] SEI, IISD, ODI, Climate Analytics, CICERO, and UNEP. (2019). The Production Gap: The discrepancy between countries' planned fossil fuel production and global production levels consistent with limiting warming to 1.5°C or 2°C. http://productiongap.org/

8 Narrabri Underground Stage 3 and Climate Change

241) The Narrabri Coal Mine is an existing underground thermal coal mine located approximately 25 km southeast of Narrabri and approximately 60 km northwest of Gunnedah. Coal production first commenced in 2010. Stage 2 of the existing mine has been extracting coal by longwall methods since June 2012 and allows for the production and processing of up to 11 million tonnes per annum (Mtpa) of run-of-mine (ROM) coal until July 2031. **The Project proposes to continue longwall mining in a major southern extension area beginning in 2022 (or year of approval) until 2044, resulting in an additional ROM coal production of 107 Mt compared to the currently approved Narrabri Mine, with a maximum ROM coal production 11 Mtpa.**[270,271]

242) The Environmental Impact Statement (EIS)[272] submitted was later amended with a report (hereafter Amended EIS Report)[273] that included a section (Section 3.3 of the Amened EIS Report) considering possible reduction in GHG from the project, and a revision of original GHG emissions from the Project (contained as Appendix C of the Amended EIS Report). The revised GHG calculations in Appendix C of the Amended EIS Report (hereafter, the Jacobs Report) were performed by the Jacobs Group, and are dated 31 May 2021.

243) Throughout the Amended EIS Report for the Project, the impact of its GHG emissions and the context in which they are placed are described as a fraction of the total emissions of the globe, Australia or NSW.

244) **In the Assessment of Impacts from the earlier Project EIS,**[274] **it is claimed that** Section 6.17.3 of that **assessment would "provide a comparison of the Project emissions to**

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[270] Narrabri Underground Mine Stage 3 Extension Project, Environmental Impact Statement (EIS), Introduction. Accessed at: https://www.planningportal.nsw.gov.au/major-projects/project/10731
[271] Narrabri Underground Mine Stage 3 Extension Project EIS, Project Description. Accessed at: https://www.planningportal.nsw.gov.au/major-projects/project/10731
[272] Narrabri Underground Mine Stage 3 Extension Project EIS. Accessed at: https://www.planningportal.nsw.gov.au/major-projects/project/10731
[273] Narrabri Stage 3 Project – Amendment Report. Accessed at: https://www.planningportal.nsw.gov.au/major-projects/project/10731
[274] Narrabri Underground Mine Stage 3 Extension Project (EIS), Section 6, Assessment of Impacts. Accessed at: https://www.planningportal.nsw.gov.au/major-projects/project/10731

relevant greenhouse gas emissions reduction targets." In fact, **no such comparison is given**. Instead, the Australian Commonwealth 2030 emissions target (see paragraph 206) is mentioned, as is an NSW "aspirational" goal of reaching net zero emissions by 2050.

245) In this Report, **I aim to provide a deeper, more relevant analysis, in which the emissions from the Project *are* compared to what is required to achieve the 2030 emission reduction targets of Australia and NSW.** In addition, **I assess the implications of the Project for achieving the primary Paris Agreement goal.** Finally, **I comment on the economic analysis provided in the Project EIS regarding the economic costs of climate change, including those caused by the Project, and indicate how they are inappropriate for predicting climate damages.**

8.1 Greenhouse Gas Emissions from the Project

246) In order for different GHGs to be expressed in a common unit (namely, Mt CO_2-e), the Jacobs Report used the common Global Warming Potential (GWP) approach (see paragraph 39), using values from an August 2019 publication from the Australian Government.[275] **These GWP values**, which are 1, 25 and 298 for CO_2, CH_4, and N_2O, respectively, **are out of date.** They **do not agree do not agree with NGER regulations**,[276] which are: 1, 28 and 265 for CO_2, CH_4, and N_2O, respectively, **nor do they agree with the most recent scientifically derived values** of: 1, 29.8, 273 for a 100-year timescale or 1, 82.5, 273 for a 20-year timescale.[277] As most of the Project's Scope 1 emissions are from methane (CH_4), the most important consequence of this outdated choice for GWP values is an underestimation of Scope 1 emissions as measured in Mt CO_2-e.

247) Consequently, throughout this Report and in the figures and tables that follow, **I have used the GHG emission estimates for the Project given in the Jacobs Report (assuming**

[275] Department of Energy and Environment (August 2019) National Greenhouse Account Factors. Accessed at: https://www.industry.gov.au/data-and-publications/national-greenhouse-accounts-factors-2019

[276] See Division 2, Section 7 of https://www.legislation.gov.au/Details/F2020C00673

[277] Forster P., T. et al. (2021) The Earth's energy budget, climate feedbacks, and climate sensitivity, Chapter & of Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Table 7.15, accessed at: https://www.ipcc.ch/report/sixth-assessment-report-working-group-i/

flaring of pre-drainage gas), with the exception that I have applied NGER GWPs in order to bring the Scope 1 estimates in agreement with the currently legislated value for the GWP of methane. A summary of these values, for Scopes 1, 2 and 3 emissions, are provided in Table 5 below. Scope 1 emissions will all be emitted in NSW; Scopes 1 and 2 will be emitted in Australia, and most of Scope 3 will be emitted by the end user of the coal products. **All three emission scopes have an equal effect on the climate of NSW on a per tonne basis, but due to the magnitude of Scope 3 emissions, Scope 3 dominates.**

Table 5: Estimated emissions from the Narrabri Stage 3 Project over various time periods

Category of Emissions ($Mt\ CO_2$-e)	Annual Average over lifetime	Total in period 2022 – 2030 inclusive	Total in period 2022 – 2044 inclusive
Scope 1	1.50	11.40	34.46
Scope 2	0.12	1.18	2.79
Scope 3	19.81	194.0	455.6
All Scopes	**21.43**	**206.6**	**492.9**

Table 5 Notes: The last two rows are given to four significant figures (in Mt CO2-e) and are for periods inclusive of the indicated beginning and ending years. The table assumes a putative approval in calendar year 2022.

248) The **average annual Scope 1 GHG emissions from the Project would be 1.50 Mt CO_2e**. This corresponds to 1.2% of NSW's total emissions in 2019. However, as NSW (presumably) meets its 2030 emissions target and begins to approach net zero by 2050, the Project will form a higher percentage of the State's annual emissions, reaching 4% or more in some years.

249) Figure 34 compares the notional emissions trajectory of the Project with a trajectory for NSW that meets the State's 2030 and 2050 emission targets, in a simple linear manner. **Despite the apparently small contribution of the Project compared to the emissions trajectory of NSW, I will show** in the next section **the exceedingly negative effects the emissions of the Project would have on the ability of the country and the State to meet 2030 emissions targets.**

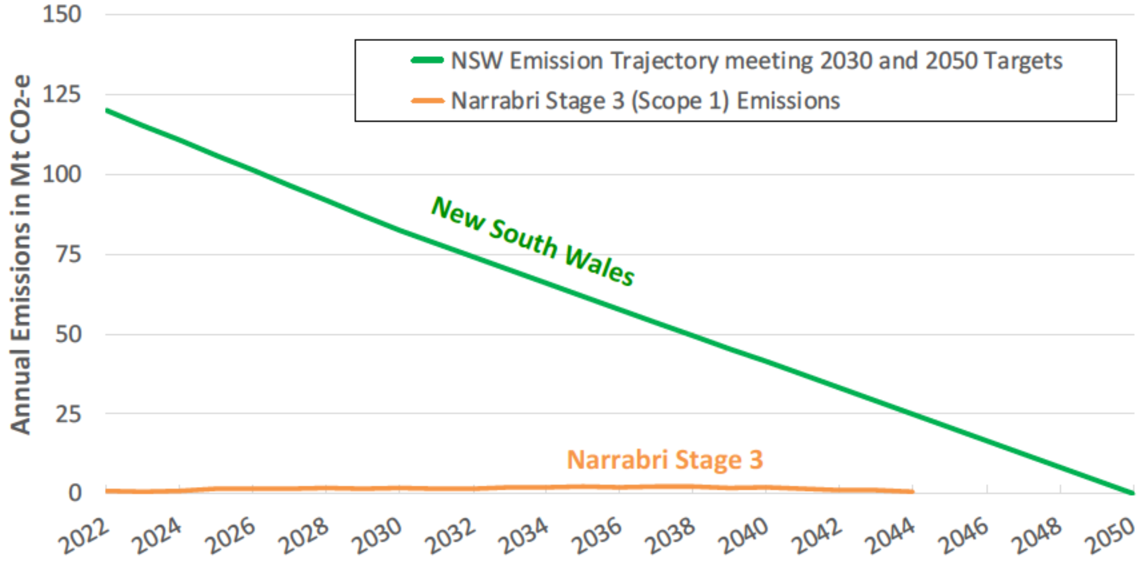

Fig. 34: Comparison of a simple (linearly-falling) Scope 1 emissions trajectory for New South Wales that meets its 2030 and 2050 targets (green) and the Scope 1 emissions trajectory of the Narrabri Stage 3 Project (gold). As Section 8.2 will demonstrate, the effect of the Project is much larger than a cursory examination of these two trajectories might seem to imply.

8.2 Implications of the Project for National and State Emissions Targets

250) **Comparisons to current emissions or to emissions targets set by governments in a given year are often used as a proxy for assessing climate change impact.** Such comparisons are an **imperfect and often misleading measure for climate impact assessments** because:

a) Current levels of emissions are already causing dangerous levels of climate change,

b) Emission targets may not reflect the actual speed, magnitude or risk of climate change,

c) Regional targets that count only regional (Scope 1) emissions, ignore the real consequences of any Scope 3 emissions from local activities on local climate, and

d) A similar argument could be made for any number of projects, whose cumulative effect would then exceed the intent of setting the target in the first place.

251) In Table 6 below, **annual Project GHG emissions are compared not only to the current levels of annual GHG emissions for Australia and for NSW, but also to the size of annual emissions *reduction* that will be required annually from 2022 in order for the country and the State to achieve their respective 2030 GHG emission targets.** Values are expressed both in Mt CO_2-e, and as a percentage.

252) The most recent values Australian and NSW emissions are taken from the National Greenhouse Gas Inventory[278] at the time of writing of this Report, namely for the year 2019. In calculating the annual reductions required from 2022 to meet 2030 emission targets, it has been assumed that 2020 CO_2-e emissions will be 88.9% of those from 2019 due to COVID restrictions, and that 2021 CO_2-e emissions be 91.5% of those in 2019. These assumptions are based on global changes in CO_2 (only) emissions in 2020 and 2021 compared to 2019 levels.[279, 280]

Table 6: Average effect of Project on meeting 2030 emission reduction targets

	Annual Quantity	**Narrabri Underground Stage 3 Average Annual Contribution**
Australia's projected 2021 direct emissions (Scope 1)*	484.06 Mt CO_2-e	1.62 Mt CO_2-e or 0.33% (Scopes 1 & 2)
AUS 2030 Target Annual *change* from 2022 required to meet 26% reduction on 2005 levels (624.2 MtCO_2-e) by 2030	– 2.46 Mt CO_2-e	1.40 Mt CO_2-e or + 56.9% in the wrong direction
New South Wales projected 2021 direct emissions (Scope 1)*	124.91 Mt CO_2-e	1.50 Mt CO_2-e or 1.2% (Scope 1 only)
NSW 2030 Target Annual *change* from 2022 required to meet 50% reduction on 2005 levels (165.0 MtCO_2-e) by 2030	– 4.71 Mt CO_2-e	1.27 Mt CO_2-e or + 26.9% in the wrong direction

**Table 6 Note: Paragraph 252) explains how emissions were projected forward to 2021.*

253) Results of this analysis are displayed in Table 6, which shows that the average annual (Scope 1 + Scope 2) **emissions** from the **Project** 1.62 Mt CO_2-e **are approximately 0.33% of Australia's current annual emissions**. The Project, through Scope 1 emissions directly attributable to NSW, **would add approximately 1.2% to NSW's current annual emissions, a sum equivalent to the total current emissions of nearly 100,000 individual NSW residents**, when considering the State's emissions on a per capita basis.

[278] https://ageis.climatechange.gov.au/
[279] Friedlingstein, P. et al. (2020) Global Carbon Budget 2020, Earth Syst. Sci. Data, 12, 3269-3340, https://doi.org/10.5194/essd-12-3269-2020
[280] Friedlingstein, P. et al. (2021) Global Carbon Budget 2021, submitted to Earth Syst. Sci. Data, https://doi.org/10.5194/essd-2021-386

254) **A more relevant, measure, however, is to compare the annual emissions from the Project to the annual emissions *reduction* required in order for Australia and NSW to meet their 2030 targets.** The Australian 2030 target, if approached linearly, requires an average *new reduction* of 2.46 $MtCO_2$-e per year, year on year, from 2022 up to and including 2030. In other words, to meet its stated 2030 Paris NDC, Australia will need to not only maintain its reduction from the previous years, but find another *further reduction* of 2.46 $MtCO_2$-e each year through 2030.

255) In comparison, the Project would *add* an average of 1.40 $MtCO_2$-e in every one of those years. **Thus, despite being operational for only a portion of this decade, the Narrabri Underground Stage 3 Project alone would make Australia's 2030 target one and one-half times more difficult to meet**, since with it, Australia would need to find 3.86 $MtCO_2$-e (instead of 2.46 $MtCO_2$-e) of new emission reductions each year through 2030.

256) **The sizeable effect that Scope 1 and Scope 2 emissions from the Project would have on Australia's 2030 and 2050 GHG targets – despite being a small fraction of current Australian emissions – is shown in Fig. 35**. For this figure, which is aimed at illustrating the approximate effect of the Project on stated Australian policy goals, it is assumed that Australia meets its 2030 emission reduction target on a linear path beginning in 2022, and then meets its net-zero target in 2050 on a linear trajectory beginning in 2030.

257) Meeting the NSW's 2030 target will require an annual new *reduction* of about 4.71 $MtCO_2$-e per year, year on year, whereas the Project would *add* 1.27 $MtCO_2$-e in Scope 1 emissions every year to 2030 on average**. Thus, if the Project were to proceed,** NSW would need to find a total of 5.98 $MtCO_2$-e (rather than 4.71 $MtCO_2$-e) new emission reductions each year through 2030, and **the difficulty of meeting the State's 2030 target would be increased by more than 25%.**

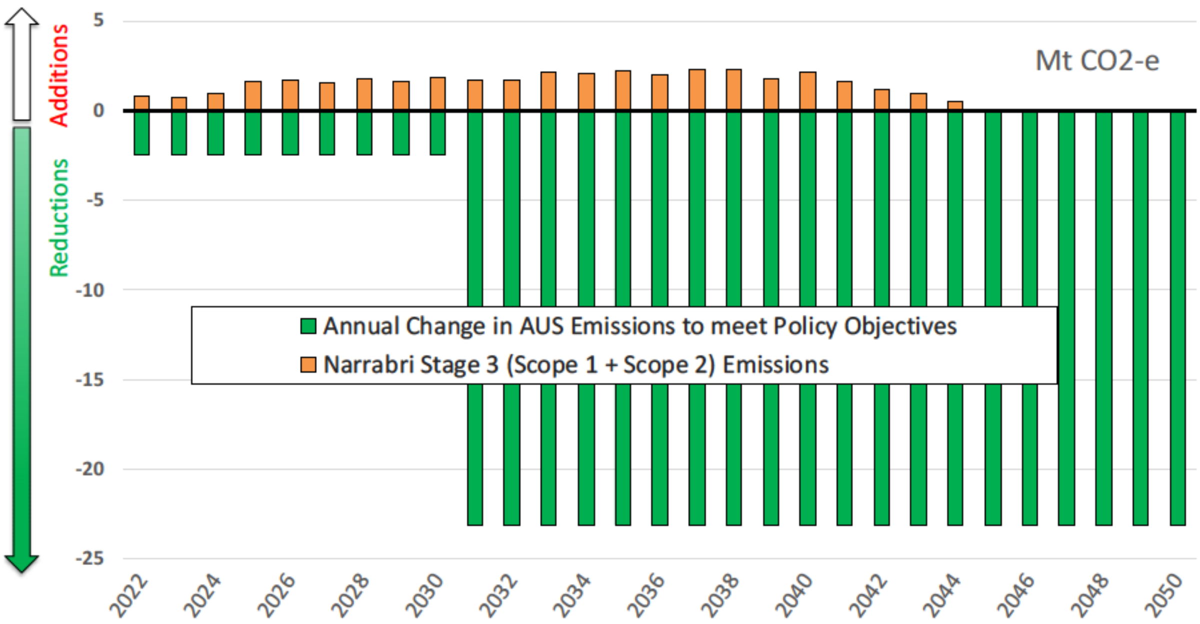

Fig. 35: Annual Scopes 1+2 emissions from the Narrabri Stage 3 Project (gold) compared to the annual reductions necessary in a simple linear model in order for Australia to meet its stated 2030 and 2050 GHG reduction targets (green). Despite being a small percentage of current Australian emissions, Project emissions are sizeable compared to the emissions reduction task required by national policy.

258) Figure 36 illustrates the magnitude of the Project emissions compared to reductions required to meet NSW's 2030 and 2050 targets. Comparison of Figs. 34 and 36 graphically illustrates why **it is misleading to consider only the fraction of a Project's emissions to current State emissions, rather than to the climate emissions policy of the State, particularly one with relatively ambitious targets.**

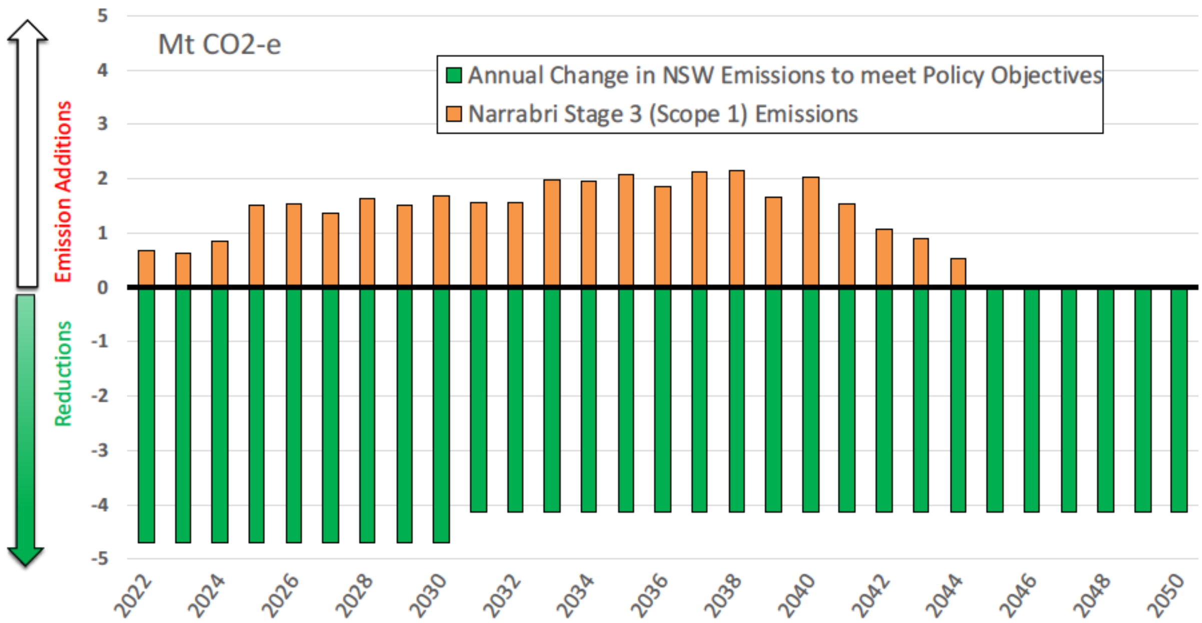

Fig. 36: Size of annual NSW Scope 1 emissions from the Narrabri Stage 3 Project (gold) compared to the annual reductions necessary in a simple model in order for New South Wales to meet both its stated 2030 and 2050 targets in the linear fashion illustrated in Fig. 34 (green).

259) An oft overlooked aspect of continued and increased coal mining is the emissions produced *after* the mine is closed or abandoned. Recent work[281] shows that methane emissions from the growing population of abandoned mines will increase faster than those from active ones. By considering the number, size and depth of coal mines, the type of coal, the rate of abandonment, and end-stage measures (such as whether mine is flooded), it has been estimated **that abandoned mine methane accounted for 17% of total global coal mining emissions in 2010**. These emissions will grow in time, and will do so faster if coal mining development increases rather than declines. **If the Project is approved, it will continue to emit additional methane long after the mine is closed.**

260) The NSW Department of Planning and Environment Assessment Report[282] for the Project (hereafter Departmental Assessment), which recommends approval of the Project, states that while the proponent "currently has approval to mine until 2031, it is seeking approval for Stage 3 now as it would allow it to efficiently change the extraction sequence for the southern set of longwall panels by mining longer panels**."**

261) **Whereas approval of Stage 3 now – 9 years before its current mining approval ends – may offer some advantage to the proponent, such an approval now would disadvantage the government and people of NSW by locking in additional GHG emissions long before a secure indication that the State's 2030 emissions target will be reached.**

8.3 Why Approving the Project is Inconsistent with warming well below 2°C

262) The phrase \`well below 2°C' is widely known to be associated with the UNFCCC Paris Agreement[283] commits signatories to "**keeping a global temperature rise this century well below 2°C above pre-industrial levels** and to pursue efforts to limit the temperature

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[281] Kholod, N. et al. (2020) Global methane emissions from coal mining to continue growing even with declining coal production. Journal of Cleaner Production, 256, 120489. Accessed at: https://www.sciencedirect.com/science/article/pii/S0959652620305369?via%3Dihub

[282] NSW Department of Planning and Environment Assessment Report (January 2022), Narrabri Underground Mine Stage 3 Extension Project , State Significant Development SSD-10269, Accessed at: https://www.planningportal.nsw.gov.au/major-projects/project/10731

[283] UN (2015), Paris Agreement, Accessed from https://unfccc.int/sites/default/files/english_paris_agreement.pdf

increase even further to 1.5°C." But this would be **the scientifically advisable goal whether the Paris Agreement existed or not, because (a) it is still achievable from a carbon budget point of view** (see Section 7.2) **and (b) temperatures of 2.0°C and above are associated with grave consequences and compounding risks to ecosystems and humans** (see Section 0).

263) **The most important step to achieving this goal is to dramatically reduce the production of fossils fuels – the overwhelming cause of anthropogenic climate change** (see Section 26)). **The deepest and swiftest reduction must occur in coal production** (see Fig. 26), which must drop worldwide by a minimum 67% between 2020 and 2030 for a flip-of-coin chance (50%) of holding warming to 1.5°C.[284] Coal production must drop by a minimum of 36% in this period to hold warming to 2°C (with a 67% chance). Consequently, **to hold warming to well below 2°C, coal production must drop by *considerably more* than 36% on 2020 levels by 2030, which is less than 8 years away**. Simply put, approving new coal mines or extensions to new ones is not consistent with holding warming to 2°C, let alone warming *well below* 2°C.

264) In 2020, NSW mined 200 Mt of black coal.[285] **In order to align its production with the requirements for a trajectory consistent with holding warming well below 2°C**, **NSW must cut production by** about 50% (chosen to be intermediate between the minimum amounts for 1.5°C and 2.0°C quoted in paragraph 263) on 2020 levels by 2030, requiring a reduction of **about 10 Mt coal per annum**. **Over this period, the Project, if approved, would be *adding* more than 9 Mt coal per annum on average[286] to NSW's Production Gap.** This size of this effect is illustrated in Fig. 37, showing that Project would be producing coal at a rate comparable to the reductions required for NSW to close its coal Production Gap in line with the Paris Agreement global warming target.

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[284] SEI, IISD, ODI, E3G, and UNEP (2021) The Production Gap Report: 2021 Report, using data provided in Supplementary Information.
https://productiongap.org/2021report/

[285] Australian Government (2021) Australian Energy Statistics, including Table I4, Dept of Industry, Science, Energy and Resources, September 2021. Accessed at:
https://www.energy.gov.au/publications/australian-energy-update-2021

[286] Using a coal production profile from the Jacobs Report

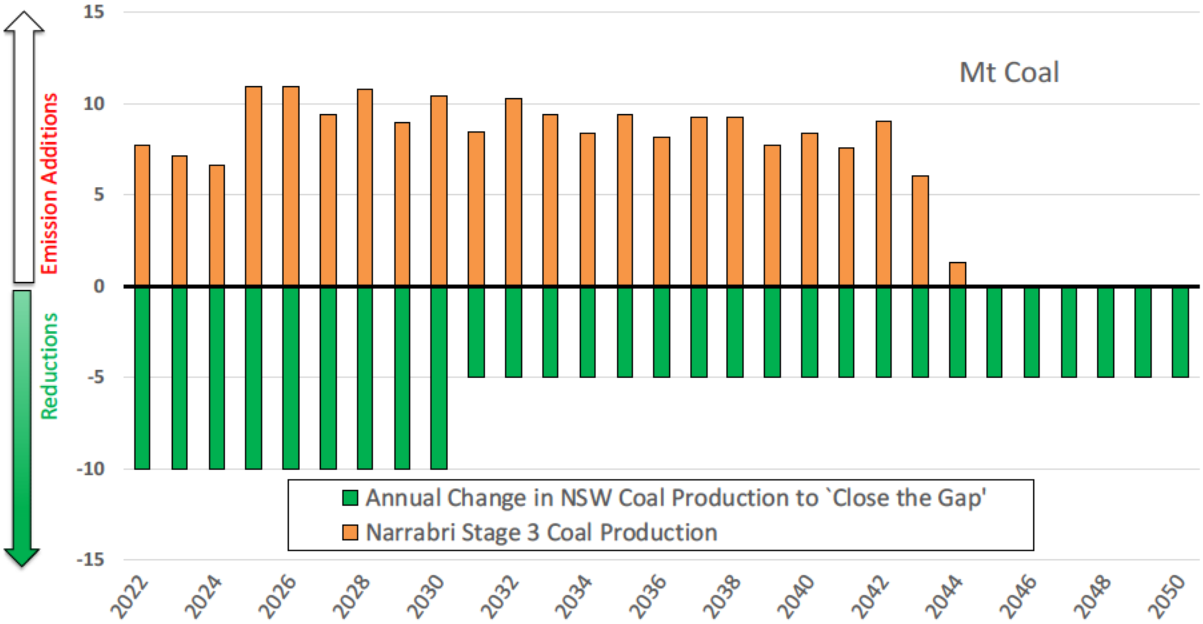

Fig. 37: Annual coal production from Narrabri Stage 3 Project (gold) compared to the annual reductions necessary in a simple linear model in order for NSW to close its coal Production Gap in a manner consistent with the Paris Agreement (green). See paragraph 264) for details.

265) Furthermore, closing NSW's coal production gap will take place against background of other recently approved coal development projects in NSW that themselves are adding to the future coal production trajectory of the State. Some of these projects[287] are listed in Table 7 below.

Table 7: Recently approved coal development projects in NSW.

Approved Project	Proponent	Consent Until	Maximum ROM Coal per annum (Mt)
Mangoola Continued Operations	Mangoola Coal Operations Pty Ltd	31 Dec 2030	13.5
Maxwell Underground	Maxwell Ventures (Management) Pty Ltd	30 Jun 2047	8.0
Rix's Creek South	Bloomfield Collieries Pty Ltd	12 Oct 2040	3.6
Russell Vale Underground Expansion	Wollongong Coal Ltd	5 years from commencement	1.2
Tahmoor South	Tahmoor Coal Pty Ltd	31 Dec 2033	4.0
United Wambo	United Collieries Pty Limited	21 Aug 2042	10.0
Vickery Extension Project	Vickery Coal Pty Ltd	12 Aug 2045	10.0
TOTAL			**50.3**

[287] All data from NSW IPC website at: https://www.ipcn.nsw.gov.au/projects

266) Although the numbers in the rightmost column of Table 7 are for maximum allowed run-of-the-mine (ROM) takes, these data make clear that **recently approved coal mine operations in NSW could be added 50 Mt coal annually to the State's production over a period in which a *reduction* of 10 Mt per year is needed to be consistent with warming well-below 2°C**. **Approving the Project would increase this possible addition to 60Mt coal per annum from now to 2030.**

267) As mentioned previously (see paragraph 197), the IEA's global energy roadmap[288] for achieving a net zero pathway by 2050 includes as a headline determination: **No new oil and gas fields approved for development; no new coal mines or mine extensions; no new unabated coal plants approved for development, beginning in 2021. It is 2022, and the Project is an application for a coal mine extension in NSW.**

[288] IEA (2021) Net Zero by 2050: A Roadmap for the Global Energy Sector, accessed at: https://www.iea.org/reports/net-zero-by-2050

8.4 Other Important Considerations

8.4.1 A word about Scope 3 Emissions

268) Although the *National Greenhouse and Energy Reporting Act 2007* (the NGER Act)[289] does not require reporting of Scope 3 emissions for Australian entities, all emissions arising directly or indirectly from an activity lead to global warming and climate change, regardless of where they are emitted. Thus, **from a scientific perspective, all emissions, including Scope 3 emissions** released when fossil fuels are combusted by any end user, **must be included** when considering environmental and social effects (such as human health), including local environmental and social effects. **To do otherwise is to assume that the fuel is never used for its intended purpose.**

269) The Departmental Assessment of the Project states (at their paragraph 393), "***In terms of orthodox GHG emissions accounting, only Scope 1 and Scope 2 GHG emissions are within the control of an entity, and therefore only they are able to be directly controlled or otherwise managed by a consent authority****. It is a fundamental principle of accounting to avoid double counting, and it must be noted that one entity's Scope 3 emissions are another entity's Scope 1 emissions. More straightforwardly, GHG emissions associated with burning coal to produce energy are accounted for at the international powerplants where that combustion takes place*."

270) I do not agree with Departmental advice given in paragraph 268) in two important respects. First, Scope 3 emissions from the Project would be affected were the Project not approved; namely there would be no Scope 3 emissions (or Scope 1 or 2) from the Project. Thus, should the Project not be approved, it would be an example of a consent authority clearly exercising direct control of (putative) Scope 3 emissions.

271) Second, the Departmental advice given in paragraph 269) **is irrelevant when evaluating the full climate impact of the Project on NSW**. This Report is concerned first and foremost with analysing the environmental and social (which includes economic)

[289] Accessed at: https://www.legislation.gov.au/Details/C2019C00044

implications of consent to a particular development application. The manner in which signatories of the Paris Agreement report GHG emissions is irrelevant in this context.

272) The Department's advice in paragraph 269) states that there is an `orthodox' approach for GHG accounting. **In fact, placing the GHG emissions from an activity into a social or environmental context can be done in different ways**, depending on the consideration of the overall goal. **A key component of the consideration is whether or not the emissions are seen as a local output**, divorced from other global social and environmental issues, or whether they are seen **in an inextricably connected global context that, in turn, affects local climate impacts**.

273) Three common-used approaches to human GHG emissions accounting in the scientific literature[290] include:

a) **Territorial, or geographic, accounting**, which focuses on *where* the GHG emissions are actually emitted,

b) **Consumption-based accounting** (sometimes called carbon footprint accounting), which focusses on the *end consumers* of these commodities and services, and

c) **Production-based accounting**, which focuses on the *entities, developments or actions* that *produce* the commodities and services that generate the GHG emissions.

274) In principle, the total GHG emissions for the world could be calculated by any of these methods, and if done carefully and completely, each calculation would result in the same global number. Total global human GHG emissions over time are what determines global warming and anthropogenic climate change. **From a scientific perspective, it is immaterial where the emissions occur, which entities produce the emitting `economic goods', or who consumes them.**

275) **In large part due to the activities of the United Nations Framework Convention on Climate Change (UNFCCC), which has promoted global cooperation to reduce GHG emissions, including the UN Paris Agreement,[291] regional accounting has become**

[290] See, for example, Chen, Z-M. et al. (2018) Nature Communications, 9, 3581, and references therein. Accessed at: https://www.nature.com/articles/s41467-018-05905-y

[291] UN (2015), Paris Agreement, accessed at: https://unfccc.int/sites/default/files/english_paris_agreement.pdf

particularly well known. As nations constitute the UN and are signatories to the Paris Agreement, it is natural that for this purpose national (geographical) entities account for the GHGs emitted within their own borders, and substantial tools have been developed to do so. Emissions outside of national borders, for example those involved in international travel and freight are, however, more difficult to account in this method.

276) Due to the global nature of the world's economy in goods and services, both consumption-based and production-based accounting must consider international trade.

277) Consumption-based accounting can be useful in allowing consumers (individuals, corporations and governments) to assess how their own choices through the procurement of goods and services can reduce GHG emissions leading to climate change.

278) **Production-based accounting traces the GHG emissions back to their source in the production of goods and services, which is particularly instructive in identifying which goods and services are currently contributing to the bulk of global GHG emissions.**

279) Throughout this Report, I refer to either geographical accounting (e.g., in Sections 7.1 and 8.2 when referring to policy targets) or production-based accounting (e.g., in Sections 7.3, 7.4.3, 7.5.1, and 8.3 when referring to the Production Gap and the positive climate impact NSW can have in reducing its fossil fuel productive.)

280) **Within GHG accounting schemes, it is essential not to double count, and this Report does not do so, but considers these matters separately**. When considering policy, Scope 3 emissions are not added to Scope 1 emissions in the geographical accounting method, and emissions from burning the Australian coal exported to India is not counted both in Australia and in India (for example), in the production-based accounting.

281) The Departmental Assessment states: "*Scope 3 GHG emissions for the Project are significant. However, they would constitute a very small contribution towards climate change at the global scale. The accounting of these Scope 3 GHG emissions would be undertaken by the entities and nations where the Project's product coal is combusted*." To my mind, **the question is not who will do the GHG accounting** (in relation to the calculation of NDCs under the Paris Agreement), **but rather who will take action on the damage caused by GHGs** (specifically, here, in relation to the Project's impact on the environment of NSW).

282) **In my opinion, one question for the Independent Planning Commission is whether approving the Project will result in GHG emissions that unnecessarily, and in some cases irreversibly, damage the environment of NSW**. **I would contend that the answer is yes, regardless of where the Project's GHG emissions occur geographically**. Project Scope 3 emissions have an identical effect on NSW's future climate – on a tonne per tonne basis – as do the Project Scope 1 emissions.

8.4.2 Project's Climate Costs to State, Country and Globe much Higher than reported in EIS

283) It is clear that economic damages due to climate change are large and increasing rapidly. The economic cost of climate change to Australia is estimated to have doubled since the 1970s,[292] with about $35 billion in losses reported in the 2010s. This is expected to rise **if emissions are not curbed sharply. Annual damages from** extreme weather, along with sea-level rise and other impacts of **climate change upon Australia, could exceed $100 billion by 2038, and exceed $1.89 trillion by 2050**.[293]

284) Another recent report[294] suggests that **even under a low emissions scenario the cost of natural disasters in Australia will increase from $38 billion annually now to at least $73 billion annually by 2060**. Given that this estimate is about double that made by the same group four years earlier, it is reasonable to expect that these estimates will only grow with time. Importantly, the report found that the **area stretching from South East Queensland to North East NSW is expected to face the greatest increase in costs from natural disasters as the frequency and severity of some natural disaster events increases.**

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[292] Steffen, W. and Bradshaw, S. (2021) Hitting Home: The Compounding Costs of Climate Inaction, and references cited therein. Climate Council of Australia Ltd. Accessed at: https://www.climatecouncil.org.au/resources/hitting-home-compounding-costs-climate-inaction
[293] Kompas, T. cited in Silvester B. (2020) Trillions up in smoke: The staggering economic cost of climate change inaction. New Daily, 10 September 2020. https://thenewdaily.com.au/news/national/2020/09/10/economic-cost-climate-change based on the modelling framework set out in Kompas, T., Pham, V., Che, T. (2018) The effects of climate change on GDP by country and the global economic gains from complying with the Paris Climate Accord. Earth's Future 6 https://doi.org/10.1029/2018EF000922
[294] Australian Business Roundtable for Disaster Resilience and Safer Communities (2021) Special report: Update to the economic costs of natural disasters in Australia. Accessed at: http://australianbusinessroundtable.com.au/our-research

285) Any justifiable estimate of the **cost to New South Wales resulting from climate change is likely to be an underestimate** because:

a) **Not all damages due to climate change can be quantified** (including those due to crossing irreversible thresholds in the Earth System as described in subsection 4.8 of this Report).

b) **Not all quantifiable damages can be fully described by an `economic cost'** (e.g., deaths or mental suffering caused by climate change).

c) As our understanding of the impacts of climate change continues to evolve, we realise that **high impacts are occurring at lower global warming values than previously thought** (see paragraph 145) and Fig. 20).

286) Nevertheless, attempts have been made to estimate **the `Social Cost of Carbon**,' that is, **the value of the net damage caused to society by adding a tonne of carbon dioxide ($CO_2$) into the atmosphere**. **The Social Cost of Carbon is not the same as a `price on carbon' that may be introduced by government policies or prices related to emissions trading schemes or carbon `offsets.' These are policy instruments, not assessments of climate damage.**

287) A 2018 survey of the scientific literature yielded a **median global Social Cost of Carbon of 417 USD per tCO_2, with a `reasonable' (66% confidence) range of 177–805 USD.**[295] **It is important to note that a large amount of research on increasing climate change costs is yet to be factored into these studies.**

288) **Converting the median value of 417 USD per tCO_2 in 2018 to Australian dollars in 2022 (adjusting for inflation) yields 600 AUD per tCO_2 for the Social Cost of Carbon**. This value is actually a substantial underestimate since the research cited[296] does not take into account costs associated with adaptation and mitigation to climate change, biodiversity loss, cultural loss, climate effects with very long-term consequences (sea level rise and ocean acidification) and long-term restructuring of the economy. **Most importantly, such**

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[295] Ricke, K., Drouet, L., Caldeira, K. and Tavoni, M. (2018) Nature Climate Change, 8, 895-900. Accessed at: https://www.nature.com/articles/s41558-018-0282-y

[296] Ricke, K., Drouet, L., Caldeira, K. and Tavoni, M. (2018) Nature Climate Change, 8, 895-900. Accessed at: https://www.nature.com/articles/s41558-018-0282-y

estimates ignore the possibility of crossing tipping points in the climate system, in which case the social costs would be unthinkable and incalculable.

289) Appendix L of the Project EIS is an economic assessment for the Project prepared by AnalytEcon on behalf of Narrabri Coal Operations Pty Ltd (hereafter, the AnalytEcon Report), which includes a section on economic costs associated with GHGs from the Project.[297]

290) The AnalytEcon Report states that it "*has been prepared in accordance with the NSW Government's 'Guidelines for The Economic Assessment of Mining and Coal Seam Gas Proposals' (NSW Government 2015) (the EA Guidelines) and the 'Technical Notes supporting the Guidelines for the Economic Assessment of Mining and Coal Seam Gas Proposals' (NSW Government 2018)*. Reference to these documents is made in support of the approach taken in the AnalytEcon Report to:

a) only consider Scope 1 and 2 emissions from the Project, and

b) use market prices to value the cost of GHG emissions, and

c) only the consider the `NSW share of the costs' associated with increased GHG emissions, which is done by considering the fraction of global gross domestic product attributable to the NSW Gross State Product (GSP).

291) On this basis, the **AnalytEcon Report states that the incremental social costs of the GHG emissions associated with the Project** using EUA futures prices **is around $860,000** in net present value (in 2020) terms. This value is then listed as an `externality' in the final analysis to arrive at a net change in GSP of $799 million attributed to the Project.

292) Whilst my area of expertise is not economics, I do have experience in examining matters related to the Social Cost of Carbon and on that basis make the following observations:

a) **From a scientific perspective, global climate damages from a Project should include all its GHG emissions (Scopes 1, 2 and 3).**

[297] Narrabri Underground Mine Stage 3 Extension Project (EIS), Appendix L, Economic Assessment. Accessed at: https://www.planningportal.nsw.gov.au/major-projects/project/10731

b) **Market `prices' do not reflect climate damages.**

c) **The market values used in the AnalytEcon Report are, nevertheless, considerable underestimates of current values (at the time of writing this Report).**

293) Specifically, the AnalytEcon Report uses forecast prices of European emission allowances (EUAs) of \$34.78 per tCO_2-e in December 2022 and \$39.55 per tCO_2-e in December 2029. Yet **on 17 February 2022, the EUA Futures Price**[298] **stood at** 86.44 Euros per tCO_2-e, or **136.42 AUD per tCO_2-e, nearly three and one-half times the value used by the AnalytEcon Report for seven years hence.**

294) Furthermore, the US *policy* value for the Social Cost of Carbon of \$20.97 per tCO_2-e quoted for 2022 by the AnalytEcon Report has been superseded; in 2022 it stands at 79 USD per tCO_2-e for the US-recommended 2.5% discount rate for decisions involving important intergenerational benefits or costs.[299] This **current US policy value for the cost of GHG emissions translates to 110.19 AUD per tCO_2-e, more than five times that used in the AnalytEcon Report.**

295) **Applying a recent median scientific value for the Social Cost of Carbon**[300] (see paragraph 288) of 600 AUD per tCO_2-e to the **full (Scopes 1, 2 and 3) lifetime emissions of the Project (492.9 Mt CO_2-e) yields at least 296 billion AUD of global damages**. If this were to be apportioned to NSW on the basis of fraction of world economy using 0.31% as in the AnalytEcon Report, the **cost to NSW of the GHGs resulting from approval of the Project would be in excess of 917 million AUD, more than 1000 times the amount used in the economic assessment in the Project EIS**.

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[298] As given by https://ember-climate.org/data/carbon-price-viewer/

[299] US IWG (2021) Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990. Accessed at: https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf

[300] Ricke, K., Drouet, L., Caldeira, K. and Tavoni, M. (2018) Nature Climate Change, 8, 895-900. Accessed at: https://www.nature.com/articles/s41558-018-0282-y

8.4.3 Departmental Recommended Conditions of Approval

296) The NSW Department of Planning and Environment has prepared a draft Development Consent document with recommended conditions of approval[301] (hereafter, Conditions of Approval); conditions related to GHG emissions are contained in items B12, B16, B17, B18 and B19 of that document.

297) The relevant portion of condition B12 is a requirement to "improve energy efficiency and minimise Scope 1 and Scope 2 GHGEs generated by the development." Condition B16 sets out performance measures for minimisation of GHG emissions; condition B17 outlines consequences if the Planning Secretary is of the opinion that performance measures have been `exceeded,' which I take to mean `not complied with.' Condition B18 outlines the manner in which that the applicant must create a "Fugitive Emissions Minimisation Plan;" condition B19 states that applicant must implement any such plan approved by the Planning Secretary. My focus in this Report will be on conditions B16, B17 and B18.

298) The performance measures in condition B16 also place limits on fugitive emissions intensity (related to Scope 1) and also include a Scope 2 measure to "minimise CO_2-e emissions by using electricity generated by renewable or carbon neutral energy sources where reasonable and feasible." The limits on fugitive emission intensities are:

a) Less than 0.215 tonnes CO_2-e emitted from the development per tonne of ROM coal per calendar year, or a lower emissions intensity as determined under condition B18.

b) Less than 0.205 tonnes CO_2-e emitted from the development per tonne of ROM coal per calendar year (5-year rolling average), or a lower emissions intensity as determined under condition B18.

c) Less than 0.155 tonnes CO_2-e emitted from the development per tonne of ROM coal over the life of extraction of ROM coal (including any period of suspension of ROM coal extraction), or a lower emissions intensity as determined under condition B18.

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[301] NSW Department of Planning and Environment (2022) Recommended Development Consent, Narrabri Underground Mine Stage 3 Extension Project (SSD-10269), Accessed at: https://pp.planningportal.nsw.gov.au/major-projects/projects/narrabri-underground-mine-stage-3-extension-project

299) With respect to the condition on Scope 2, I note that **if *all* Scope 2 emissions were eliminated by this performance measure, an expected 2.79 Mt CO_2-e would be saved** relative to values given in the EIS. This **corresponds to about 7.48% of total putative Project Scope 1 + Scope 2 emissions, and 0.565% of total emissions (all Scopes) from the Project**.

300) Condition B17 states (in full): "In determining compliance with the performance measures in Table 3, the Planning Secretary will take into account *any atypical or abnormal operating conditions which hindered or prevented mining operations, any exceedances already offset (or required to be offset) under other applicable Commonwealth or State requirements, changes in Global Warming Potentials and/or any voluntary offsetting of CO_2-e emissions by the Applicant*. If, following this consideration, the Planning Secretary determines that the Applicant *has still exceeded* any of these performance measures, then the Applicant *must offset the excess CO_2-e emissions* within 6 months of the Planning Secretary's determination, using a mechanism to the satisfaction of the Planning Secretary." [emphasis mine]

301) Annual expected values for run of mine (ROM) coal production and Scope 1 emissions from fugitives are given in the Jacobs Report, and can be used to calculate the fugitive emission intensity expected by the applicant when the amended EIS was submitted. Modified values using the current NGER value for the GWP of methane (such as used in this Report) can also be calculated. These are plotted in Fig. 38, together with the 5-year rolling averages for these values, and the Departmental performance measure limits as detailed in paragraph 298).

302) The average emissions intensity over the lifetime of the Project is 0.140 according to the values derived from the EIS, and 0.157 as derived in this Report; the recommended performance measure is 0.155.

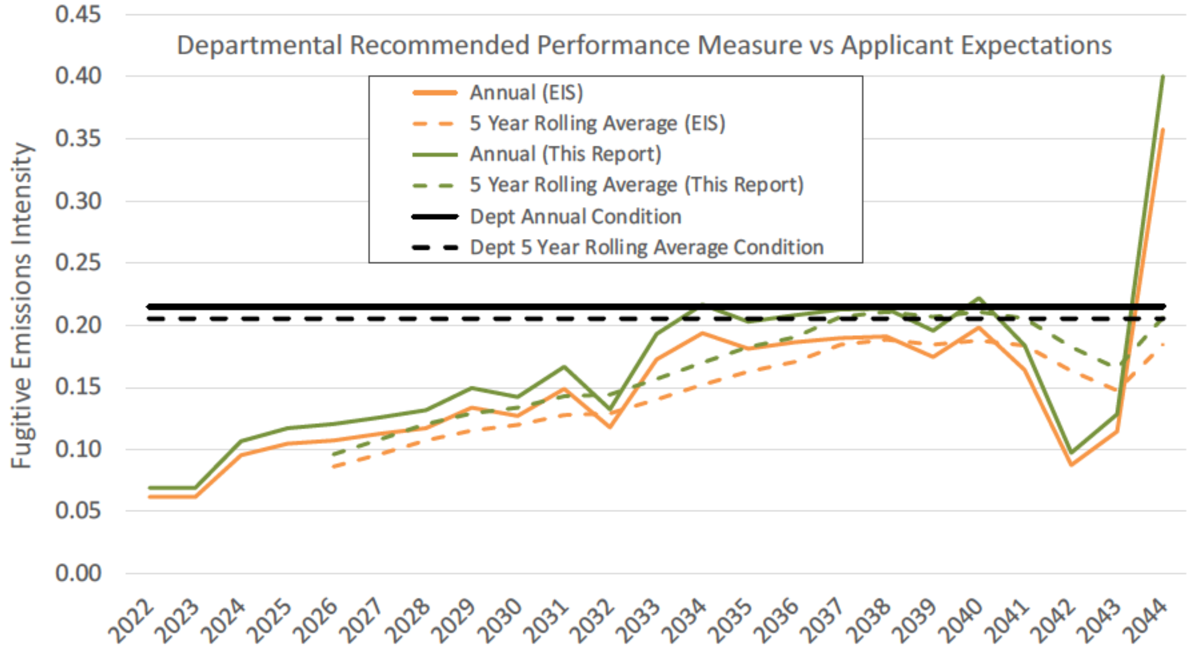

Fig. 38: Scope 1 fugitive emission intensities from the Project as derived from applicant EIS (gold), from this Report using current NGER values for the GWP of methane (green), and as defined as a performance measure in the Conditions of Approval (black). Solid lines denote annual values; dashed lines denoted rolling 5-year averages.

303) As can be seen from Fig. 38, Project fugitive emission intensities as derived from the EIS easily comply with the recommended performance measure, both for annual and 5-year rolling averages, in all years except the final year of operation. Even using the current (and higher) value for the GWP of methane, as done in this Report, the expected fugitive emission intensities of the Project fall below or skim directly on the boundaries of the recommended performance measure, save in the final year.

304) **This means, apart from the very last year of operations, the recommended fugitive emissions performance measure does not reduce emission intensities below what was already in place as the expected plan for the Project. In fact, in many years, the Project could substantially increase fugitive emission intensity from its EIS plan, and still meet the performance measures.**

305) Furthermore, the constraint is placed on emission intensity, not actual emissions. **This means that the Project could increase its coal production (whilst staying with the proposed 11 Mtpa limit and maintaining emission intensity), which would actually increase the amount of Scope 1 emissions from the amount given in the EIS, and yet still satisfy the recommended performance measure.**

306) **As for the last year, for which enforcing compliance may be problematic, fugitive emission intensities** of the sort shown for year 2044 in Fig. 38, **would presumably invoke condition B17** (see paragraph 299). In this case, according to the Conditions of Approval the applicant may plead `atypical or abnormal operating conditions' and if this was not to the satisfaction of the Planning Secretary, the emissions in excess must be `offset.' **However, Project Scope 1 fugitive emissions are expected to be their lowest in 2044 over the whole operating period (even if the fugitive emissions *intensity*) is at its highest. According to the Jacobs Report, full Scope 1 emissions for 2044 are expected to be 0.481 Mt CO_2-e; only the fraction exceeding the emissions would be require `offsetting.'**

307) Two points should be made with regard to `offsetting' Scope 1 emissions from the Project that are considered by the Planning Secretary to exceed the performance measures set out in paragraph 298):

a) **Offsets do not reduce global GHG emissions. At best, they negate emissions that have already been released. In order to do so, they must remove the same *amount*, and the same *type* of GHG at the same *time* as the original emissions occur, and they must come from an activity that would not have occurred without the offset.** These conditions are required for a true offset because different GHGs have different GWPs and because the original emission will cause some warming in the time that elapses between the emission and a later offset.

b) **GHGs from fossil fuels cannot be `offset' – in a climate sense – with biological GHG sinks.**[302] This is because the GHG emissions from fossil fuels add GHGs back into the atmosphere that have not been there for millions of years. Offsets that use biological systems (such as trees, for example) to draw down GHGs (particularly carbon dioxide) will return most of those gases to the atmosphere when they die and decompose in natural cycles of years to centuries. In addition to being temporary, biological offsets

[302] Watts, K. (2015) Fossil and biological carbon: a tonne is not a tonne, Carbon Market Watch. Accessed at: https://carbonmarketwatch.org/publications/policy-brief-fossil-and-biological-carbon-a-tonne-is-not-a-tonne/

can take time to take effect and may be subject to later destruction through changed land practices or, for example, fires exacerbated by climate change itself.

308) Consequently, offsets **are a poor substitute for ensuring that fossil GHGs are not released, or minimised to the greatest extent possible, in the first place. Together with the weak performance measures on Scope 1 emissions proposed, I conclude that that conditions B16 and B17 are unsatisfactory in that they do not require the applicant to reduce emissions outlined in the EIS, and in fact allow leeway for even more Scope 1 emissions** than described there by applicant.

309) The Fugitive Emissions Minimisation Plan outlined in condition B18 of the Conditions of Approval requires that "Within 12 months of commencing development under this consent and then every 3 years during the life of mining operations (and any period of suspension of ROM coal extraction and/or processing), unless otherwise agreed by the Planning Secretary, the Applicant must prepare a Fugitive Emissions Minimisation Plan to the satisfaction of the Planning Secretary." Several detailed points then describe how the Plan is to be developed, what must information must be included, and which technologies must be reviewed. Specifically, the Plan must:

a) "include a 3-year action plan to investigate and implement reasonable and feasible measures to minimise fugitive emissions, including proposed research/ pilot programs;

b) include (in all plans prepared subsequent to 2035) reasonable and feasible measures proposed to minimise fugitive emissions from the site during rehabilitation and following mine closure; and

c) propose any reasonable and feasible lower fugitive emissions intensity performance measures than set in Table 3 to minimise Scope 1 and Scope 2 GHGEs from the development."

310) Condition B19 (in its entirety) is: "The Applicant must implement the Fugitive Emissions Minimisation Plan as approved by the Planning Secretary."

311) **Given that condition B18 specifies that the applicant write the Fugitive Emissions Minimisation Plan, including what it considers to be "reasonable and feasible," it is not clear to what extent writing and implementing such a plan would reduce Scope 1 emissions from the Project.**

312) What is clear is one approach that is being considered by the applicant at this point in time. Jacobs Report updates the GHG inventory for the Project by incorporating ``the most recent fugitive emissions modelling data'' to show ``the potential emission reductions that may be achieved from flaring these emissions.'' The results are shown in Table 3 of the Jacobs Report which indicate that **over the life of the Project, total emissions of 0.219 Mt CO_2-e may be avoided by flaring of pre-drainage gas. This represents about 0.64% of all expected Scope 1 emissions and 0.045% of total emissions (all Scopes) estimated for the Project** (refer to paragraph 247) and Table 5).

313) **Taken together, I conclude that recommended Conditions of Approval would not significantly reduce Scope 1 and Scope 2 GHG emissions from that indicated in the Project EIS, and in fact, allow the possibility that they could be increased. Importantly, the Conditions of Approval do not address the most important component of the Project's emissions that affect the environment of NSW: Scope 3 emissions.**

314) Furthermore, **by recommending approval of the Project now –** 9 years before the current mining approval ends – **the government and people of NSW are disadvantaged by not having access to critical information that may affect the decision, including a much better indication of the future market for coal, the results of future studies and research described by the applicant in the EIS and in condition B18, and** (see paragraph 261) a **secure indication of whether or not the State's 2030 emissions target will be met.**

8.4.4 Precautionary Principle and Intergenerational Equity

315) As this Report has set out in Sections 4 and 5, **the effects of climate change – which is caused by anthropogenic GHG emissions – are already serious; they are in fact dangerous. Furthermore, some of these effects are already irreversible** (see e.g., Sections 4.8 and 4.9) **and more will become so with even small amounts of additional warming beyond that of 1.5°C which is already locked in** (see e.g., paragraphs 80), 122), 123) and 150).

316) **Every tonne of GHG emission leads to (more) dangerous warming. It is not possible to know which amount, from which source, will precipitate environmental subsystems, including those in NSW, to tip irreversibly.**

317) In this context, the Precautionary Principle certainly applies. I disagree with the statement in Appendix K[303] of the EIS that "*The contribution to social issues of the greenhouse gas emissions attributed to the Project is considered negligible*", and the statement in the Departmental Assessment that "*the recommended performance measures and other conditions of consent would provide appropriate protection for water resource and environmental values and minimise the potential for any serious or irreversible environmental damage*."

318) **The argument** put by the Project proponent[304] **that Project emissions represent a very small fraction of national or global emissions is irrelevant and misleading. If individual consent authorities around the world were to accept this argument and act upon it to approve fossil fuel expansion projects, the climate change predicament would, *per force*, continue to worsen.**

319) **The climate change externalities of the Project will be borne disproportionately by younger and future generations, with no clear recourse or path to remediation.** Given that any future emissions 'lock in' extra warming, there is no possibility for true `remediation' of the climate damages caused by emissions from the Project. These damages include deterioration in the health, diversity and productivity of the environment, and have direct consequences for human health and livelihood.

320) Using standards developed by Whitehaven, the Environmental Risk Assessment[305] for the Project EIS rates the risk of "*Scope 1, 2 and 3 Greenhouse Gas emissions resulting from construction and operation of the Project*" as `Moderate' taken to mean that the risk is at "*risk acceptance threshold*." These same standards describe a `Catastrophic' risk as one that results in "*unconfined detrimental impact requiring long-term recovery leaving major residual damage (typically years)*" or economic damage of more than "*50 million AUD*."

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[303] Narrabri Underground Mine Stage 3 Extension Project (EIS), Appendix K, Social Impact Statement. Accessed at: https://www.planningportal.nsw.gov.au/major-projects/project/10731

[304] See, e.g., Narrabri Underground Mine Stage 3 Extension Project (EIS), Appendix K, Social Impact Statement, and the Jacobs Report in the EIS Amendment Report. Accessed at: https://www.planningportal.nsw.gov.au/major-projects/project/10731

[305] Narrabri Underground Mine Stage 3 Extension Project (EIS), Appendix O, Environmental Risk Assessment. Accessed at: https://www.planningportal.nsw.gov.au/major-projects/project/10731

321) Given the long-term, unconfined, and in some cases irreversible, damage of climate change that will be exacerbated by the Project, and the case put that these damages to NSW will be far in excess of 50 million AUD (see paragraph 295), **I conclude that the Project represents a Catastrophic risk, as defined by the** Project's **own risk assessment in the EIS.** The recommended approach in such cases, according to the Project's risk assessment is: "Immediate attention needed, stop the job."

322) Unabated climate change is likely to be greatest overall threat to the environment and people of New South Wales (NSW) because it is comprehensively dangerous, global, fundamental, rapid, compounding, self-reinforcing, has delayed effects and, in some cases, is irreversible (see Section 4). In my opinion, **environmentally sustainable development is development that avoids the catastrophic risks that climate change poses, noting the special nature of climate change as a risk not only to the natural environment, but also human health, well-being and livelihoods.**

323) The Department Assessment states: "*The Department acknowledges that the mining of coal and its combustion is a major contributor to anthropogenic climate change, which has the potential to impact future generations,*" and yet concludes: "*The Department considers that the Project does not conflict with the principle of intergenerational equity.* ***That is, the health, diversity and productivity of the environment would be maintained or enhanced*** [emphasis mine]."

324) **This Report has sought to detail some of the reasons why the health, diversity and productivity of the NSW environment will not be maintained or enhanced by the Project, but will, in fact, be damaged by its approval, including in ways that are irreversible.**

Respectfully submitted 23 February 2022,

[redacted]

Professor Penny D Sackett

Appendix A: Brief Provided to Author by the EDO

See attached pages.

Environmental Defenders Office

28 January 2022

Professor Penny D Sackett
Strategic Advisory Services

By email: [redacted]

CONFIDENTIAL AND PRIVILEGED

Dear Prof Sackett

Brief to Expert – Narrabri Underground Mine Stage 3 Extension Project (SSD 10269) Public Hearing

1. We act for Lock the Gate in relation to the proposed Narrabri Underground Mine Stage 3 Extension Project (SSD 10269) (**Project**) by Narrabri Coal Operations Pty Ltd.

2. The Narrabri Coal Mine is an existing underground thermal coal mine located approximately 25 kilometres (**km**) south-east of Narrabri and approximately 60 km north-west of Gunnedah. Coal production using bord and pillar and partial extraction methods commenced in 2010. Stage 2 of the existing mine has been extracting coal by longwall methods since June 2012 and allows for the production and processing of up to 11 million tonnes per annum (**Mtpa**) of run-of-mine (**ROM**) coal until 26 July 2031. The Project proposes to continue longwall mining in a major southern extension area until 2044. The Project also seeks the continued use of existing underground and surface infrastructure, including use of the existing Coal Handling and Preparation Plant (**CHPP**) at 11 Mtpa.

3. The Project has now been referred to the Independent Planning Commission (**IPC**) for determination with a public hearing. Our client wishes to ensure the IPC receives independent expert advice on the Project. Accordingly, our client wishes to retain your services to act as an expert, to provide an expert report for submission to the IPC and to present your expert views to the IPC public hearing.

Primary purpose to provide independent expert advice

4. We note as a preliminary matter that our primary purpose in briefing you to prepare your report is to provide independent expert advice in your area of expertise. We do not ask you to be an advocate for our client. You are requested to prepare an independent report that is clear and well-written.

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5. In this respect, we draw your attention to Division 2 of Part 31 of the *Uniform Civil Procedure Rules 2005* (**UCPR**), and the Expert Witness Code of Conduct (**Code of Conduct**) contained in Schedule 7 of the UCPR, both of which govern the use of expert evidence in NSW Courts (**attached**). We understand that the IPC public hearing is not a Court proceeding, however, we are of the view that the same Code of Conduct should be adhered to in this instance.

6. In particular, clause 2 of the Code of Conduct states that:

   "An expert witness is not an advocate for a party and has a paramount duty, overriding any duty to the party to the proceedings or other person retaining the expert witness, to assist the court impartially on matters relevant to the area of expertise of the witness."

7. Your expert report must contain an acknowledgment that you have read the Expert Witness Code of Conduct and that you agree to be bound by it.

8. Your expert report will be used as evidence in chief of your professional opinion. Information of which you believe the decision maker should be aware must be contained in your expert report.

9. In providing your opinion to the decision maker you must set out all the assumptions upon which the opinion is based. This may include, for example, facts observed as a result of fieldwork or 'assumed' facts based on a body of scientific opinion. If the latter, you should provide references which demonstrate the existence of that body of opinion.

10. Your expert report must also set out the process of reasoning which you have undertaken in order to arrive at your conclusions. It is insufficient for an expert report to simply state your opinion or conclusion reached without an explanation as to how this was arrived at. The purpose of providing such assumptions and reasoning is to enable the decision maker and experts engaged by other parties to make an assessment as to the soundness of your opinion.

Overview of work requested

11. We request that you undertake the following work:

    a. review the documents listed below;
    b. prepare a written expert report that addresses the issues identified below ('Issues to address in your expert report'), and ensure that the work is prepared in accordance with Part 31, Division 2 of the UCPR; and
    c. appear as an expert witness at the IPC public hearing for the purpose of giving oral evidence.

Documents

12. We enclose the Code of Conduct and Part 31 Division 2 of the UCPR.

13. Full Project documentation is available at the following websites:

a. NSW Government Planning Portal: https://www.planningportal.nsw.gov.au/major-projects/project/10731
b. IPC: https://www.ipcn.nsw.gov.au/projects/2021/12/narrabri-underground-mine-stage-3-extension-project-ssd-10269.

14. The following documents relating to the Project are provided for your particular consideration:

Environmental Impact Statement

a. Executive Summary: https://majorprojects.planningportal.nsw.gov.au/prweb/PRRestService/mp/01/getContent?AttachRef=SSD-10269%2120201023T021123.529%20GMT
b. Table of Contents: https://majorprojects.planningportal.nsw.gov.au/prweb/PRRestService/mp/01/getContent?AttachRef=SSD-10269%2120201023T021124.977%20GMT
c. Section 1 - Introduction: https://majorprojects.planningportal.nsw.gov.au/prweb/PRRestService/mp/01/getContent?AttachRef=SSD-10269%2120201023T021125.593%20GMT
d. Section 2 - Project Description: https://majorprojects.planningportal.nsw.gov.au/prweb/PRRestService/mp/01/getContent?AttachRef=SSD-10269%2120201023T021126.211%20GMT
e. Section 3 - Strategic Context: https://majorprojects.planningportal.nsw.gov.au/prweb/PRRestService/mp/01/getContent?AttachRef=SSD-10269%2120201023T021127.519%20GMT
f. Section 6 - Assessment of Impacts (greenhouse gas emissions pp. 6-125 – 6-129): https://majorprojects.planningportal.nsw.gov.au/prweb/PRRestService/mp/01/getContent?AttachRef=SSD-10269%2120201023T021129.246%20GMT
g. App I - AQGHG (pp. 10-14, 24, 50-53, Appendix F): https://majorprojects.planningportal.nsw.gov.au/prweb/PRRestService/mp/01/getContent?AttachRef=SSD-10269%2120201023T021207.795%20GMT

Response to Submissions

a. Submissions Report (pp. 82-84): https://majorprojects.planningportal.nsw.gov.au/prweb/PRRestService/mp/01/getContent?AttachRef=EXH-10425089%2120210531T070053.430%20GMT.

Amendments

a. Narrabri Stage 3 Project - Amendment Report (pp. 13-18, Appendix A, Appendix B, Appendix C, Appendix D): https://majorprojects.planningportal.nsw.gov.au/prweb/PRRestService/mp/01/getContent?AttachRef=SSD-10269%2120210531T065545.008%20GMT.

Additional Information

a. RFI - Greenhouse Gas Emissions - 22 Sep 21: https://majorprojects.planningportal.nsw.gov.au/prweb/PRRestService/mp/01/getContent?AttachRef=RFI-28578842%2120210922T080152.059%20GMT

b. NCOPL Response to RFI - Greenhouse Gas Emissions - 15 Oct 21: https://majorprojects.planningportal.nsw.gov.au/prweb/PRRestService/mp/01/getContent?AttachRef=RFI-28578842%2120211015T030000.474%20GMT

c. NCOPL Response to RFI - Greenhouse Gas Emissions - 17 Dec 21: https://majorprojects.planningportal.nsw.gov.au/prweb/PRRestService/mp/01/getContent?AttachRef=SSD-10269%2120211223T010055.714%20GMT

Relevant Agency Advice

a. CAS - Advice on EIS, Submissions and Amendment Reports and Additional Information: https://majorprojects.planningportal.nsw.gov.au/prweb/PRRestService/mp/01/getContent?AttachRef=SSD-10269%2120220112T235531.298%20GMT

Department's Assessment Report

a. Department's Assessment Report (pp. vi-xv, 54-67) https://majorprojects.planningportal.nsw.gov.au/prweb/PRRestService/mp/01/getContent?AttachRef=SSD-10269%2120220119T051727.890%20GMT

d. Recommended Conditions: https://majorprojects.planningportal.nsw.gov.au/prweb/PRRestService/mp/01/getContent?AttachRef=SSD-10269%2120220119T051728.236%20GMT.

15. Please let us know as soon as possible if you require further information for the purpose of giving your expert opinion.

Issues to address in your expert report

16. We ask that your report address the following issues in regard to any climate change impacts arising as a result of the Project:

a. Please summarise any greenhouse gas emissions predicted to arise as a consequence of the Project.

b. Provide a brief description of the causes and effects of anthropogenic climate change.

c. Provide a brief description of any anthropogenic climate change already being experienced, including within the state of NSW.

d. Provide a brief description of anthropogenic climate change projections and impacts on current emissions trends.

e. In your opinion, is approval of the Project consistent with a goal of limiting anthropogenic climate change to 1.5 or well below 2 degrees Celsius above pre-industrial levels. Please provide reasoning for your response.

f. Provide any further observations or opinions which you consider to be relevant.

Key dates

17. The IPC public hearing will be held remotely from **Monday 14 February 2022** with registered speakers participating via tele- and/or videoconference.

18. To speak at the electronic public hearing, you must complete the registration form on the IPC website by no later than **12pm AEDT on Wednesday 9 February 2022**. Registration can be completed at: https://www.ipcn.nsw.gov.au/speaker_registration_form?project_id=32bf6906-1c50-4915-ba46-1ae160e57da6.

19. The IPC will accept written comments on the Project until **5pm AEDT on Monday 21 February 2022**.

20. To assist our clients to prepare for the public hearing, we request a draft of your expert advice by **Friday 11 February 2022**.

21. Please provide your final expert advice by **Friday 18 February 2022**.

Duty of confidentiality

22. Please treat your work as strictly confidential until your expert report is provided to the IPC, unless authorised by us.

Fees and Terms

23. Thank you for agreeing to provide your advice in this matter on a pro bono (volunteer) basis. EDO relies on experts such as you to assist in matters with very little financial compensation.

24. Please note the following terms:

    a. your work will only be used by EDO to relation to this matter;
    b. our client may choose to make your expert advice publicly available. Any public release of your report, whether by our client or by way of publication on the IPC's website, may result in disclosure of any works in your report over which you may claim copyright;
    c. EDO will take all reasonable steps to prevent your work being used for purposes other than that mentioned above, but we accept no responsibility for the actions of third parties;
    d. regardless of the above points, EDO may choose not to use your work; and
    e. you will not be covered by the EDO's insurance while undertaking the above tasks.

25. If you would like to discuss this brief further, please contact the author on (02) 9262 6989 or email [redacted]

We are grateful for your assistance in this matter.

Yours sincerely
Environmental Defenders Office

[redacted]

Matt Floro
Special Counsel

Reference number: S2602

Appendix B: Curriculum Vitae of Author

See attached pages.

Curriculum Vitae
PENNY D. SACKETT

Academic Address:
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[redacted]

Private Business Address:
Dr Penny D Sackett
Strategic Advisory Services

www.pennysackett.com

Born: 28 February 1956, Lincoln, Nebraska USA
Citizenship: U.S. and Australian
Permanent Residence: Australia
Languages: English: Mother Tongue; Dutch: Good knowledge; Spanish: Beginner's knowledge

Education:

1984	Ph.D. in Physics, University of Pittsburgh, PA, USA Thesis Title: *Scale Parameters for Finite Temperature Actions of Lattice Gauge Theories Coupled to Fermions*
1980	M.S. in Physics, University of Pittsburgh, PA, USA
1978	B.S. in Physics, University of Nebraska-Omaha (UNO), NE, USA
1978	Teaching certification (K-12), Physics and Mathematics, UNO, USA

Distinctions and Honours:

2019	Distinguished Alumni Award, University of Pittsburgh, USA
2016	Omaha (USA) North High Magnet School "Viking of Distinction" Award
2014	UNO College of Arts and Sciences Outstanding Alumni Award
2014	Citation for Alumni Achievement: Univeristy of Nebraska-Omaha (UNO)
2011	Opening Keynote Speaker: 2011 Adelaide Festival of Ideas, SA, Australia
2005	Univ of Canberra-Australian National Univ International Women's Day Lecturer
2004	Finalist, Telstra ACT Business Women of the Year, ACT, Australia
2003	Fellow of the UK Royal Astronomical Society *Election to the Society to honour a person eminent in the field of astronomy and not normally resident in the UK for leadership, enabling activities, etc*
2002	Harley Wood Lecturer, Astronomical Society of Australia
2000	Athena Lecturer, St. Andrews University, Scotland
1998	University of Groningen Teaching Award (Onderwijsprijs), The Netherlands
1992-1994	J. Seward Johnson Fellow, Institute of Advanced Study, Princeton, NJ, USA
1981-1982	O.H. Blackwood Award for Excellence in Teaching, University of Pittsburgh, PA, USA
1979-1981	Andrew Mellon Fellowship, University of Pittsburgh, PA, USA
1978	Summa Cum Laude, University of Nebraska-Omaha, NE, USA
1978	Most Outstanding Physics Student, University of Nebraska-Omaha, NE, USA
1978	Most Outstanding Mathematics Student, University of Nebraska-Omaha, NE
1974-1978	Dean's List, University of Nebraska-Omaha, NE, USA
1974-1978	Nebraska Regent's Scholarship, University of Nebraska-Omaha, NE, USA
1974-1978	National Merit Scholarship, University of Nebraska-Omaha, NE, USA

Professional Society Membership

Astronomical Society of Australia
International Astronomical Union
Royal Astronomical Society

Professional Activity and Appointments

2020-current	Distinguished Honorary Professor (E3), Climate Change Institute, Australian National University, Canberra, Australia *Climate change synthesis and analysis, community engagement*
2011-current	Strategic Scientific Advisor and Principal Penny D Sackett Strategic Advisory Services *Sole trader assisting governments, communities, courts and business with matters of science, climate change and sustainability*
2014-2019	Honorary Professor, Climate Change Institute, Australian National University, Canberra, Australia *Community engagement, science for policy, subnational climate change action*
2008-2014	Academic Adjunct Professor, Research School of Astronomy and Astrophysics, Australian National University, Canberra, Australia *Mentoring early career researchers*
2008-2011	Chief Scientist for Australia, DIISR, Australian Commonwealth Government, Canberra, Australia *Provision of independent, whole-of-government scientific advice, science advocacy, liaison with community, bureaucracy and state governments*
2007-2008	Professor (Level E2), Research School of Astronomy and Astrophysics, Australian National University (ANU), Canberra, Australia *Research, research training, and international research co-ordination*
2002-2007	Director, Research School of Astronomy and Astrophysics, and the Mt. Stromlo and Siding Springs Observatories, ANU, Canberra, Australia *Strategic leadership, budget, human & facility management, liaison, advocacy*
2001-2002	Chaired Professor of (Extra)Galactic Optical/Infrared Astronomy, Kapteyn Astronomical Institute, University of Groningen, The Netherlands *Research, research training, teaching, international program building*
1998-2000	Associate Professor with tenure (Universiteits Hoofd Docent), Kapteyn Astronomical Institute, University of Groningen, The Netherlands *Research, research training, teaching, international program building*
2000	Visiting Member, Institute for Advanced Study, Princeton, NJ, USA (on leave from Kapteyn Institute 1999-2000 academic year) *Research of international standing*
1999	Visiting Scientist, Anglo-Australian Observatory, Epping, Australia (on leave from Kapteyn Institute 1999-2000 academic year) *Research of international standing and international co-ordination*
1995-1997	Assistant Professor with tenure (Universiteits Docent), 75% full time Kapteyn Astronomical Institute, University of Groningen, The Netherlands *Research, research training, teaching, research program building*
1995-1997	Visiting Research Member, School of Natural of Sciences, 25% full time Institute of Advanced Study, Princeton, NJ, USA *Research of international standing*
1992-1994	Research Member & J. Seward Johnson Fellow, School of Natural of Sciences, Institute of Advanced Study, Princeton, NJ, USA *Self-directed research of international standing*

1991-1992	Program Director, Education, Human Resources and Special Programs, Div of Astronomical Sciences, National Science Foundation, Washington, DC, USA *Program management, cross-division initiatives, external liaison*
1990-1992	Research Assistant Professor, Physics and Astronomy Department, University of Pittsburgh, PA, USA *Self-directed research*
1987-1990	Adjunct Assistant Professor, Physics and Astronomy Department, University of Pittsburgh, PA, USA *Self-supported research post*
1988-1989	Visiting Scientist, Kapteyn Astronomical Institute, University of Groningen, The Netherlands *Self-directed independent research*
1987	Scientific Writing Consultant, Pittsburgh Supercomputing Center (PSC), Pittsburgh, PA, USA *Technical writing and editing*
1986-1987	Research Associate, Biological Sciences Department, University of Pittsburgh, PA, USA *Algorithm development and application to cellular activity*
1985-1986	Visiting Assistant Professor, Physics and Astronomy Department, University of Pittsburgh, PA, USA *University physics teaching*
1983-1985	Visiting Assistant Professor, Physics Department, Amherst College, MA, USA *University teaching in liberal arts setting*
Summer 1983	Science Writer Intern, *Science News* Magazine, Washington, DC, USA *Developing and writing science news stories*

Supervision of Junior Researchers

Researcher name	Sackett Supervisory Capacity	Subsequent posting
Paul Vreeswijk	1997 Honours Thesis Supervisor	Fellow, Weizmann Inst of Science, IL
Jean Philippe Beaulieu	1996-98 Postdoctoral Supervisor	Director of Research, IAP, Paris, FR
Martin Dominik	1997-99 Postdoctoral Supervisor	Reader, Univ of St Andrews, UK
Richard Naber	PhD Thesis (Co-supervisor)	Left field before completion
Scott Gaudi	2001 PhD Thesis (Co-supervisor)	Professor, Ohio State University, USA
Eduard Westra	2003 Honours Thesis Supervisor	Industrial Data Analyist, NL
Ulyana Dyudina	2004 Postdoctoral Supervisor	Assoc Scientist, Space Science Inst, USA
Jelte de Jong	2005 PhD Thesis (Co-supervisor)	Researcher, University of Groningen, NL
David Weldrake	2005 PhD Thesis Supervisor	Asst Director, M-D Basin Authority, AU
Brandon Tingley	2006 PhD Thesis Supervisor	PostDoc, Aarhus University, DK
Christine Thurl	2007 PhD Thesis Supervisor	Industrial Physicist, DE
Thomas Evans	2008 Honours Supervisor	Research Fellow, Univ of Exeter, UK
Daniel Bayliss	2009 PhD Thesis Supervisor	Asst Professor, Univ of Warwick, UK
Karen Lewis	2011 PhD Thesis (Co-supervisor)	Postdoc, Earth Life Science Inst, JP

Selected Major Experiences and Accomplishments

2011-present *As Private Strategic Scientific Advisor:*

- Sole Expert Witness in BSCA vs EPA case in NSW Land and Environment Court
- Foresight analyst for 2025 Strategic Plan of BASF, world's largest chemical producer
- Scientific Assessor for Queensland $20m Smart Futures Fund
- Analyst and advisor to Australian multi-state Climate Action Roundtable

2015-2021 *As Councillor and Chair of ACT Climate Change Council:*

- Spearheaded recommendation for interim GHG emissions targets in the ACT
- With Prof. Will Steffen, introduced carbon budget approach into ACT policy-making
- Led *Canberra's Climate-Fuelled Summer of Crisis* Report

2008-2011 *As Chief Scientist for Australia:*

- Commissioned four cross-disciplinary reports for Prime Minister's Council (PMSEIC):
  - *Challenges at energy-water-carbon intersections*
  - *Australia and food security in a changing world*
  - *Transforming learning and the transmission of knowledge*
  - *Epidemics in a changing world*
- Founded Forum of Australian Chief Scientists
- Established two-way communication tools with Australian community

2002-2007 *As Director, Research School of Astronomy and Astrophysics (RSAA)*

- Managed University department and observatory staff of 100
- Responsible for annual budget of 6M AUD plus 4M AUD in 2nd & 3rd steam funds
- Oversaw rebuild of main campus of School after devastating 2003 bush fires
- Led national effort to establish next generation telescope access for Australia
- Established ANU Planetary Science Institute, joint venture with ANU Earth Sciences
- Initiated and carried out large change process at RSAA, managing mandated 29% increase in salary costs & 20% reduction in recurrent budget
- Spearheaded entry into two major international partnerships: Giant Magellan Telescope (GMT) and Murchison Wide Field Array (MWA)
- Negotiated awards of two major instrument contracts: Gemini NIFS (II) and GSAOI
- Oversaw 80% increase in research publication rate, 50% growth in PhD student body, and increase in student completion rate while decrease in time to submission

1989-2010 *As Scientific Researcher and Team Leader in USA, NL and Australia:*

- Streamlined massive searches for transiting planets in the Milky Way
- Founded and Principal Investigator of the international PLANET Collaboration, managing collaboration of 20 scientists in 7 countries using 5 telescopes to set first limits for Jupiter-like planets around common dwarf stars, determine limb-darkening of distant stars for the very first time, and detect first terrestrial-mass (5-Earth mass) exoplanet around a normal star
- Determined 3-D distribution of dark matter around some galaxies
- Quantified relationship between structure and dark matter in Milky Way
- Determined deep cloud structure in atmosphere of Saturn

1991-1992 *As Program Director at U.S. National Science Foundation (NSF), USA*

- Managed program of small grants to fund high-risk science
- Initiated first newsletter from NSF Astronomy division (AST) to national community
- Managed all cross-division (AST + another NSF division) awards
- Responsible for all AST projects related to education and diversity
- Initiated study into factors correlated to proposal success and failure

Local, National & International Service

2015-2021	Councillor and Chair, Australian Capital Territory (ACT) Climate Change Council
2017-2020	Member, Business Advisory Board, ACT Renewable Energy Innovation Fund
2017-2019	Member, Scientific Advisory Board, Potsdam Institute for Climate Impact Research
2015	Chair, Memorandum Team, Nobel Laureate Symposium: *Climate Change, Changing Cities*
2013	Invited Speaker, 2013 Geological Society of America, Denver, CO, USA Contribution: *Elemental Cycles in the Anthropocene*
2011	Drafting Team, Nobel Laureate Stockholm Memorandum on Global Sustainability
2008-2011	As Chief Scientist for Australia, Member of: Prime Minister's Science, Engineering & Innovation Council, Executive Officer Prime Minister's Science Prize Selection Committee Educational Investment Fund Board Defence Science & Technology Organisation Advisory Board Rural Research & Development Council Higher Education Endowment Fund Assessment Panel Cooperative Research Centres Assessment Panel Climate Change Science Framework Implementation Group, Chair National Youth Science Forum, President Forum of Australian Chief Scientists, Founder and Chair
2005-2010	Board of Directors, Association of Universities for Research in Astronomy (AURA)
2006-2008	Board of Directors, Giant Magellan Telescope (GMT) Organisation
2002-2008	ANU Member Representative to AURA
2008	Australian GMT Advisory Committee to Australia Astronomy, Ltd
2003-2007	NCA Task Force on Extremely Large Telescopes (ELT)
2002-2007	National Committee for Astronomy (NCA), Australian Academy of Science
2002-2007	Australian Gemini Telescope Steering Committee
2002-2007	Board of Management for the Australian Astronomy MNRF Award
2004-2007	Chancellor's Award Committee, Australian National University (ANU)
2004-2006	Canberra Partnership Board, ACT, AU
2003-2005	University Science, Health & Engineering Research Committee, ANU
2000-2005	European OPTICON Extremely Large Telescope (ELT) Science Working Group
2004	International review team of the South African Astro-Geoscience Facilities for the NRF
2002-2003	Academic Board, Australian National University, Canberra, AU
1995-2002	Principal Investigator, International PLANET Collaboration
2001-2002	Science Advisory Committee for the Square Kilometer Array
2001-2002	Curriculum Advisory Committee for Astronomy, Kapteyn Astronomical Institute
2000-2002	European Southern Observatory (ESO) Programmes Committee, Member-at-Large
2000-2001	Chair, Stars and Planets Panel for OPTICON ELT Working Group
1996-1998	ESO Working Group on Exo-Solar Planets
1996-1998	Facilities Program Committee, Netherlands Organisation for Scientific Research

Scientific Organising and Steering Committees:

2013-2015	*Changing Climate, Changing Cities* Nobel Laureates Symposium on Global Sustainability, Hong Kong 2015 also Chair, Symposium Memorandum Drafting Team
2008	*2008 Meeting of the Astronomical Society of Australia* Perth, Australia
2006-2007	*IAU Symposium on Exoplanets: Physics, Dynamics and Evolution* Suzhou, China
2006	*Transiting Extrasolar Planets* 25-28 September 2006, MPIA, Heidelberg, Germany
2003-2004	*Planetary Timescales: Stardust to Continents* 2003 White Conference, National Academy of Sciences, Canberra, AU
2002-2003	*Extrasolar Planets: Today and Tomorrow* 30 June - 4 July 2003, IAP, Paris, France
2001-2002	*Scientific Frontiers in Research on Extrasolar Planets* 11-14 June 2002, Washington, DC, USA
2001	*The SKA: Defining the Future* 9-12 July 2001, Berkeley, CA, USA
2000-2001	*Yale Cosmology Workshop: Shapes of Galaxies and Their Halos* 28-30 May 2001, New Haven, USA
1999-2000	*Planetary Systems in the Universe: Observation, Formation and Evolution* 7-11 August 2000, Manchester, England
1998-2000	*Microlensing 2000: A New Era for Microlensing Astrophysics* 21-25 February 2000, Capetown, South Africa Chair, Scientific Organising Committee
1997-1999	*Impact of Large-Scale Photometry on the Research of Pulsating Stars* IAU Conference, 9-13 August 1999, Budapest, Hungary
1997-1999	*VLT Opening Symposium: From Extrasolar Planets to Brown Dwarfs* 1-4 March 1999, Antofagasta, Chile
1997-1998	*4^{th} International Workshop on Microlensing Surveys* 15-17 January 1998, Paris, France
1990	*Warped Disks and Inclined Rings around Galaxies* Workshop 30 May - 1 June 1990, Pittsburgh PA Scientific and Local Organising Committee

PUBLICATIONS

Over 140 publications, 65 in refereed journals, together garnering
more than 4400 scientific citations and 1000 normalised citations
(Sackett served as PhD or postdoctoral supervisor for authors in italics)

Technical Reports and Communications: Climate Change

Expert Report: On the Environmental Impact Statement of the Winchester South Project as it relates to Climate Change
Penny D Sackett
2021, Part of a submission to the Queensland Coordinator-General

Expert Report: Matter of Bushfire Survivors for Climate Action Inc v Environment Protection Authority
Affirmed as Affidavit D on 10 August 2021
Penny D Sackett
2021, Submission to the NSW Land and Environment Court, Case No. 20/106678

Expert Report: Matter of Bushfire Survivors for Climate Action Inc v Environment Protection Authority
Affirmed as Affidavit C on 5 August 2021
Penny D Sackett
2021, Submission to the NSW Land and Environment Court, Case No. 20/106678

Expert Report: Matter of Bushfire Survivors for Climate Action Inc v Environment Protection Authority
Affirmed as Affidavit B on 4 June 2021
Penny D Sackett
2021, Submission to the NSW Land and Environment Court, Case No. 20/106678

Expert Report: Matter of Bushfire Survivors for Climate Action Inc v Environment Protection Authority
Affirmed as Affidavit A on 5 March 2021
Penny D Sackett
2021, Submission to the NSW Land and Environment Court, Case No. 20/106678

The Social Cost of Carbon and Implications for the ACT
Paul Bannister, Cristopher Brack, Mark Howden, Karen Jesson, Ben Ponton, Penny D Sackett (Chair), Sophia Hamblin Wang
2021, ACT Climate Change Council, Canberra

Expert Submission: Tahmoor South Coal Extension Project (SSD 17-8845)
Objecting: On the basis of greenhouse gas implications
Addendum: Addendum in Response to Additional Material
Penny D Sackett
2020, Submission to the NSW Independent Planning Commission

Expert Report: Matter of Mullaley Gas & Pipeline Accord Inc v Santos NSW Pty Ltd; Independent Planning Commission of NSW
Affirmed as Affidavit C on 5 August 2021
Penny D Sackett
2021, Submission to the NSW Land and Environment Court, Case No. 20/363113

Expert Report: Greenhouse Gas and Climate Implications of the Narrabri Gas Project (SSD 6456)
Response to Additional Material
Penny D Sackett
2020, Submission to the NSW Independent Planning Commission

Expert Report: Greenhouse Gas and Climate Implications of the Narrabri Gas Project (SSD 6456)
Penny D Sackett
2020, Submission to the NSW Independent Planning Commission

Learning from Canberra's Climate-Fuelled Summer of Crisis
Paul Bannister, Cristopher Brack, Mark Howden, Karen Jesson, Ben Ponton, Penny D Sackett (Chair), Sophia Hamblin Wang
2020, ACT Climate Change Council, Canberra

Community Listening Report on Adaptation to Climate Crises: The Extreme Summer of 2019/20
Penny Sackett, Will Steffen and Karen Jessen
2020, ACT Climate Change Council, Canberra

Expert Submission: Tahmoor South Coal Extension Project (SSD 17-8845)
Objecting: On the basis of greenhouse gas implications
Addendum: In Response to the Greenhouse Gas Assessment of the Amended Project
Penny D Sackett
2020, Submission to the NSW Independent Planning Commission

Climate of fear: summit aims to create action consensus
S. Robson and P. Sackett
2020, in "Insight" of the Medical Journal of Australia, 2 March 2020

Expert Submission: Tahmoor South Coal Extension Project (SSD 17-8845)
Objecting: On the basis of greenhouse gas implications
Penny D Sackett
2019, Submission to the NSW Independent Planning Commission

Independent Assessment: Rix's Creek South Continuation of Mining Project (SSD 6300)
Objecting: On the basis of greenhouse gas implications
Penny D Sackett
2019, Submission to the NSW Independent Planning Commission

Who is Counting our Carbon Budget?
P.D. Sackett and W. Steffen
2019, in "Policy Forum" of the Asia and The Pacific Policy Society, 7 May 2019

What is a Carbon Budget?
Penny Sackett, Will Steffen and Karen Jessen
2018, ACT Climate Change Council, Canberra

Sub-National Climate Policies: How does the ACT compare? Part I: Report
Luke Kemp, Penny Sackett, and Frank Jotzo
2015, ACT Climate Change Council, Canberra

Sub-National Climate Policies: How does the ACT compare? Part II: Data Tables
Luke Kemp, Penny Sackett, and Frank Jotzo
2015, ACT Climate Change Council, Canberra

Refereed Scientific Publications

Elemental cycles in the Anthropocene: mining aboveground
Penny D. Sackett
2016, in Geoscience for the Public Good and Global Development: Toward a Sustainable Future, eds. G.R. Wessel and J.K. Greenberg, J.K., Geological Society of America Special Papers 520, p. SPE520-11, doi:10.1130/2016.2520(11)

HATS-3b: An Inflated Hot Jupiter Transiting an F-type Star
Daniel D. R. Bayliss et al (29 authors, including Penny D Sackett)
2013, AJ, 146, 113, arXiv:1306.0624

Endangered Elements: Conserving the Building Blocks of Life
(Invited Review) Penny Sackett
2012, Solutions, Volume 3, Issue 3

HATSouth: a global network of fully automated identical wide-field telescopes
G. Á. Bakos et al (24 authors, including *Daniel D. R. Bayliss* and Penny D. Sackett
2013, PASP, 125, 154, arXiv:1206.1391

The Frequency of Hot Jupiters in the Galaxy: Results from the SuperLupus Survey
Daniel D. R. Bayliss and Penny D. Sackett
2011, ApJ, 743, 103, arXiv:1112.0359

Confirmation of a Retrograde Orbit for Exoplanet WASP-17b
Daniel D. R. Bayliss, Joshua N. Winn, Rosemary A. Mardling & Penny D. Sackett
2010, ApJ Letters, 722, L224-L227, arXiv:1009.5061

An *a priori* Investigation of Astrophysical False Positives in Ground-Based Transiting Planet Surveys
Tom M. Evans & Penny D Sackett
2010, ApJ, 712, 38, arXiv:1002.0886

Microlensing exoplanets
Penny D Sackett
2010, Scholarpedia, 5(1):3991

The Lupus Transit Survey for Hot Jupiters: Results and Lessons
Daniel D. R. Bayliss, *David T. F. Weldrake*, Penny D. Sackett, *Brandon W. Tingley* & *Karen M. Lewis*
2009, AJ, 137, 4368, astro-ph/0903.5121

Possibility of Detecting Pulsar Moons through Time-of-Arrival Analysis
Karen M. Lewis, Penny D. Sackett & Rosemary A. Mardling
2008, ApJL, 685, L153, astro-ph/0805.4263

Lupus-TR-3b: A Low-Mass Transiting Hot Jupiter in the Galactic Plane?
David T. F. Weldrake, *Daniel D. R. Bayliss*, Penny D. Sackett, *Brandon W. Tingley*, Michaël Gillon & Johny Setiawan
2008, ApJL, 675, L37, astro-ph/0711.1746

The Frequency of Large Radius Hot and Very Hot Jupiters in ω Centauri
David T. F. Weldrake, Penny D. Sackett & Terry J. Bridges
2008, ApJ, 674, 1117, astro-ph/0710.3461

A Deep Wide-Field Variable Star Catalog of ω Centauri
David T. F. Weldrake, Penny D. Sackett & Terry J. Bridges
2007, AJ, 133, 1447, astro-ph/0610704

Resolving Stellar Atmospheres I: The Hα line and comparisons to microlensing observations
Christine Thurl, Penny D. Sackett & Peter H. Hauschildt
2006, A & A, 455, 315, astro-ph/0604088

MACHOs in M31? Absence of evidence but not evidence of absence
Jelte T.A. de Jong, Lawrence M. Widrow, Patrick Cseresnjes, Konrad Kuijken, Arlin P.S. Crotts, Alexander Bergier, Edward A. Baltz, Geza Gyuk, Penny D. Sackett, Robert R. Uglesich & Will J. Sutherland
2006, A & A, 446, 855, astro-ph/0507286

Discovery of a cool planet of 5.5 Earth masses through gravitational microlensing
J.-P. Beaulieu, et al (PLANET, OGLE and MOA, 73 authors, includ. Penny D. Sackett)
2006, Nature, 439, 437, astro-ph/0601563

The color signature of the transit of HD 209458 and discrepancies between stellar atmospheric models and observations
B. Tingley, *C. Thurl* & P. Sackett
2006, A & A, 445, L27, astro-ph/0510633

A Photometric Diagnostic to Aid in the Identification of Transiting Extra-solar Planets
Brandon Tingley & Penny D. Sackett
2005, ApJ, 627, 1011, astro-ph/0503575

An Absence of Hot Jupiter Planets in 47 Tucanae: Results of a Wide-Field Transit Search
David T.F. Weldrake, Penny D. Sackett, Terry J. Bridges, & Kenneth C. Freeman
2005, ApJ, 620, 1043, astro-ph/0411233

A Method for the Detection of Planetary Transits in Large Time-Series Datasets
David T.F. Weldrake & Penny D. Sackett
2005, ApJ, 620, 1033, astro-ph/0411234

Phase light curves for extrasolar Jupiters and Saturns
Ulyana A. Dyudina, Penny D. Sackett, *Daniel D.R. Bayliss*, Sara Seager, Carolyn C. Porco, Henry B. Throop & Luke Dones
2005, ApJ, 618, 973-986, astro-ph/0406390

A Comprehensive Catalogue of Variable Stars in the field of 47 Tucanae
David T.F. Weldrake, Penny D. Sackett, Terry J. Bridges, & Kenneth C. Freeman
2004, AJ, 128, 736, astro-ph/0405133

First Microlensing Results for the MEGA Survey of M31
Jelte T.A. de Jong, Konrad H. Kuijken, Arlin P.S. Crotts, Penny D. Sackett, Will J. Sutherland, Robert R. Uglesich, Edward A. Baltz, Patrick Cseresnjes, Geza Guyk, Lawrence M. Widrow (MEGA Collaboration)
2004, A & A, 417, 461-477, astro-ph/0307072

PLANET II: A Microlensing and Transit Search for Extrasolar Planets
Penny D. Sackett, M.D. Albrow, *J.-P. Beaulieu*, J.A.R. Caldwell, C. Coutures, *M. Dominik*, J. Greenhill, K. Hill, K. Horne, U.-G. Jorgensen, S. Kane, D. Kubas, R. Martin, J. Menzies, K.R. Pollard, K.C. Sahu, J. Wambsganss, R. Watson, A. Williams (PLANET),
in Bioastronomy 2002: Life Among the Stars, eds. R. Norris, C. Oliver & F. Stootman
2004, IAU Symposium 213 (San Francisco: ASP), 35, astro-ph/0211098

High-Precision Limb-Darkening Measurement of a K3 Giant Using Microlensing
D.L. Fields, M.D. Albrow, J.H. An, *J.-P. Beaulieu*, J.A.R. Caldwell, D.L. DePoy, *M. Dominik*, *B.S. Gaudi*, A. Gould, J. Greenhill, K. Hill, S. Kane, R. Martin, J. Menzies, R.W. Pogge, K.R. Pollard, P.D. Sackett, K.C. Sahu, P. Vermaak, R. Watson & A. Williams (PLANET), and J.-F. Glicenstein & P.H. Hauschildt
2003, ApJ, 596, 1305, astro-ph/0303638

A Short, Non-Planetary Microlensing Anomaly: Observations and Lightcurve Analysis of MACHO 99-BLG-47
M.D. Albrow, J. An, *J.-P. Beaulieu*, J.A.R. Caldwell, D.L. DePoy, *M. Dominik*, *B.S. Gaudi*, A. Gould, J. Greenhill, K. Hill, S. Kane, R. Martin, J. Menzies, R.W. Pogge, K.R. Pollard, P.D. Sackett, K.C. Sahu, P. Vermaak, R. Watson, A. Williams (PLANET)
2002, ApJ, 572, 1031, astro-ph/0201256

First microlens mass measurement: PLANET photometry of EROS BLG-2000-5
J. An, M.D. Albrow, *J.-P. Beaulieu*, J.A.R. Caldwell, D.L. DePoy, *M. Dominik*, *B.S. Gaudi*, A. Gould, J. Greenhill, K. Hill, S. Kane, R. Martin, J. Menzies, R.W. Pogge, K.R. Pollard, P.D. Sackett, K.C. Sahu, P. Vermaak, R. Watson, A. Williams (PLANET)
2002, ApJ, 572, 521, astro-ph/0110095

Detection of a Thick Disk in the Edge-on Low Surface Brightness Galaxy ESO 342-G017
Mark J. Neeser, Penny D. Sackett, Guido De Marchi, & Francesco Paresce
2002, A&A, 383, 472, astro-ph/0201141

Microlensing Constraints on the Frequency of Jupiter-Mass Companions: Analysis of Five Years of PLANET Photometry
B.S. Gaudi, M.D. Albrow, J. An, *J.-P. Beaulieu*, J.A.R. Caldwell, D.L. DePoy, *M. Dominik*, A. Gould, J. Greenhill, K. Hill, S. Kane, R. Martin, J. Menzies, *R.M. Naber*, J.-W. Pel, R.W. Pogge, K.R. Pollard, P.D. Sackett, K.C. Sahu, P. Vermaak, *P.M. Vreeswijk*, R. Watson, A. Williams (PLANET)
2002, ApJ, 566, 463, astro-ph/0104100

The PLANET microlensing follow-up network: Results and prospects for the detection of extra-solar planets
M. Dominik, M. D. Albrow, *J.-P. Beaulieu*, J. A. R. Caldwell, D. L. DePoy, *B. S. Gaudi*, A. Gould, J. Greenhill, K. Hill, S. Kane, R. Martin, J. Menzies, *R. M. Naber*, J.-W. Pel, R. W. Pogge, K. R. Pollard, P.D. Sackett, K. C. Sahu, P. Vermaak, R. Watson, A. Williams (PLANET collaboration)
2002, Planetary and Space Science, 50, 299-307, astro-ph/9910465

Interpreting Debris from Satellite Disruption in External Galaxies
Kathryn V. Johnston, Penny D. Sackett and James S. Bullock
2001, ApJ, 557, 137, astro-ph/0101543

Hα Equivalent Width Variations across the Face of Microlensed K Giant in the Galactic Bulge
M.D. Albrow, J. An, *J.-P. Beaulieu*, J.A.R. Caldwell, *M. Dominik*, J. Greenhill, K. Hill, S. Kane, R. Martin, J. Menzies, K.R. Pollard, P.D. Sackett, K.C. Sahu, P. Vermaak, R. Watson, A. Williams (PLANET), and P. Hauschildt
2001, ApJL, 550, L173, astro-ph/0011380

Limits on the Abundance of Galactic Planets from Five Years of PLANET Observations
M.D. Albrow, J. An, *J.-P. Beaulieu*, J.A.R. Caldwell, D.L. DePoy, M. Dominik, *B.S. Gaudi*, A. Gould, J. Greenhill, K. Hill, S. Kane, R. Martin, J. Menzies, *R.M. Naber*, J.-W. Pel, R.W. Pogge, K.R. Pollard, P.D. Sackett, K.C. Sahu, P. Vermaak, *P.M. Vreeswijk*, R. Watson, A. Williams (PLANET)
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